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U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Predicted Values of the Viscosity and Thermal Conductivity Coefficients of Nitrous Oxide

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Predicted Values of the Viscosity and Thermal Conductivity Coefficients of Nitrous Oxide

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Note on Units

The results in this paper are given in British Engineering units at the specific request of the sponsor. Selected results, however, are also given in SI units to conform with the policy of the National Bureau of Standards to promote the SI system.

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PREDICTED VALUES OF THE VISCOSITY AND THERMAL CONDUCTIVITY COEFFICIENTS OF NITROUS OXIDE*

Howard J. M. Hanley

The viscosity and thermal conductivity coefficients of nitrous oxide are calculated for temperatures between 180 and 900 K (330 to 1600°R) for pressures to 23 MPa (∿ 3500 psi). Tables of values are presented. Two mixtures with carbon dioxide are also discussed. These transport coefficients (for the pure fluid and for the mixtures) were predicted from thermodynamic data. Details of the prediction procedure are presented. Estimates of the accuracy of the tabular values are ± 6% for the viscosity and ± 8% for the thermal conductivity.

Key words: Carbon dioxide; corresponding states; mixtures; nitrous oxide; prediction; thermal conductivity; transport property; viscosity.

1. INTRODUCTION

In this report we discuss the transport coefficients — the viscosity coefficient (η) and the thermal conductivity coefficient (λ) — of nitrous oxide, N_2O. Tables of values are presented from 0.1 to 23 MPa (approximately 15 to 3500 psi) for temperatures between 180 and 900 K (approximately 330 to 1600°R). Two selected mixtures of nitrous oxide and carbon dioxide are considered briefly.

Nitrous oxide is a common substance yet the transport coefficients have not been measured over a wide temperature and pressure range. In fact, the data are so scarce we prefer to obtain the coefficients by calculation [1]: the limited data are used only to check the procedure where possible.

2. DATA SURVEY

A bibliography of data sources for the thermodynamic and transport properties of nitrous oxide was prepared by the Cryogenic Data Center, National Bureau of Standards, Boulder, Colorado. The appropriate references for the

viscosity and thermal conductivity are as follows: viscosity coefficient, references [2]-[8]; thermal conductivity coefficient, references [9]-[23].

We have correlated the transport coefficients of several simple fluids [Ar, O_2, N_2, CH_4, C_2H_6] in a series of papers [24]. Criteria were set up to evaluate data critically, and an equation to represent the coefficients was proposed. Unfortunately, this procedure cannot be applied to nitrous oxide at this time because suitable data are not available for analysis. We have been able to find only two data sets for the dense gas and liquid, those from references [19] and [23], for the thermal conductivity. The other references cover the dilute gas only.

As remarked, therefore, we decided to present tables based on a prediction procedure, which will be outlined in the next section.

3. PREDICTION METHOD

The method used is an application of a procedure introduced in detail in reference [1]. An outline is given here.

As is well known, if classical two-parameter corresponding states applies to two fluids designated α and o, one can write the viscosity of one at a density (ρ) and temperature (T), in terms of the other:

$$\eta_\alpha(\rho,T) = \eta_o(\rho_{\alpha,o}, T_{\alpha,o}) \left(\frac{M_\alpha}{M_o}\right)^{1/2} \left(\frac{\rho_\alpha^c}{\rho_o^c}\right)^{2/3} \left(\frac{T_\alpha^c}{T_o^c}\right)^{1/2} \tag{1}$$

Also for the thermal conductivity,

$$\lambda_\alpha(\rho,T) = \lambda_o(\rho_{\alpha,o}, T_{\alpha,o}) \left(\frac{M_o}{M_\alpha}\right)^{1/2} \left(\frac{\rho_\alpha^c}{\rho_o^c}\right)^{2/3} \left(\frac{T_\alpha^c}{T_o^c}\right)^{1/2} \tag{2}$$

In the above equations, M is the molecular weight, and $\rho_{\alpha,o}$ and $T_{\alpha,o}$ are the density and temperature respectively, for fluid o to correspond to the density and temperature for fluids α. The variables can be expressed in terms of the critical parameters, ρ^c and T^c; thus, $\rho_{\alpha,o} = \rho(\rho_o^c/\rho_\alpha^c)$ and $T_{\alpha,o} = T(T_o^c/T_\alpha^c)$. The

coefficients η_o and λ_o also have to be scaled as shown in equations (1) and (2). It is common practise to calculate the coefficients for α given those for o — which is then treated as a reference fluid.

Equations (1) and (2) can be extended for a mixture, x, if it is assumed that the mixture can be represented as an equivalent pure fluid — the one-fluid approximation — and that the mixture is "conformal," that is, all components obey the two-parameter corresponding states law. Hence one can write

$$\eta_x(\rho,T) = \eta_o(\rho_{\alpha,o}, T_{\alpha,o}) \left(\frac{M_x}{M_o}\right)^{1/2} \left(\frac{\rho_x^c}{\rho_o^c}\right)^{2/3} \left(\frac{T_x^c}{T_o^c}\right)^{1/2} \tag{3}$$

and similarly for the thermal conductivity, λ_x. Equation (3) can be derived under well-defined assumptions [25]. The derivation further yields a set of mixing rules:

$$(\rho_x^c)^{-1} = \sum_\alpha \sum_\beta x_\alpha x_\beta (\rho_{\alpha\beta}^c)^{-1} \tag{4}$$

and

$$T_x^c (\rho_x^c)^{-1} = \sum_\alpha \sum_\beta x_\alpha x_\beta T_{\alpha\beta}^c (\rho_{\alpha\beta}^c)^{-1} \tag{5}$$

where x_α is the mole fraction of α. The mixing rule used in this work for the mass is $M_x = \sum_\alpha x_\alpha M_\alpha$ (which differs slightly from that proposed in reference [25]). The $\alpha\beta$ variables of equations (4) and (5) are given by

$$T_{\alpha\beta}^c = \xi_{\alpha\beta} (T_{\alpha\alpha}^c T_{\beta\beta}^c)^{1/2} \tag{6}$$

and

$$(\rho_{\alpha\beta}^c)^{-1} = \psi_{\alpha\beta} \left[\frac{1}{2} (\rho_{\alpha\alpha}^c)^{-1/3} + \frac{1}{2} (\rho_{\beta\beta}^c)^{-1/3}\right]^3 \tag{7}$$

where $\xi_{\alpha\beta}$ and $\psi_{\alpha\beta}$ are binary interaction parameters, which are best obtained from experiment.

The mixing rules, equations (6) and (7), are consistent with the mixing rules derived for thermodynamic properties using the one-fluid approximation. If, therefore, the binary interaction parameters are assumed to be those valid for thermodynamic properties, one has a procedure to predict the viscosity and thermal conductivity coefficients of mixture x, given the equivalent coefficients of the reference fluid.

Equations (1)-(3) are not general in that two-parameter corresponding states is invalid for polyatomic fluids, or for mixtures containing polyatomic molecules. The situation is, of course, paralleled with respect to the thermodynamic properties and has been discussed extensively in this latter context. For example, a recent approach due to Leland [26] and to Rowlinson [27], is of interest here. According to Leland and Rowlinson a third parameter, ω — which can be taken as the Pitzer acentric factor — is introduced, but the framework of simple two-parameter corresponding states is preserved, if one considers the scaling functions

$$f_{\alpha\alpha,o} = (T^c_{\alpha\alpha}/T^c_o)\,\theta_{\alpha\alpha,o}\;; \qquad h_{\alpha\alpha,o} = (\rho^c_o/\rho^c_{\alpha\alpha})\,\phi_{\alpha\alpha,o} \tag{8}$$

for fluid α with respect to o. The terms $\theta_{\alpha\alpha,o}$ and $\phi_{\alpha\alpha,o}$ are called shape factors and are weakly varying functions of temperature and density:

$$\theta_{\alpha\alpha,o} = 1 + (\omega_{\alpha\alpha}-\omega_o)F(T,\rho); \qquad \phi_{\alpha\alpha,o} = 1 + (\omega_{\alpha\alpha}-\omega_o)G(T,\rho) \tag{9}$$

where $\omega_{\alpha\alpha}$ and ω_o are acentric factors for fluids α and o, respectively. Using the shape factors, the compressibility factor (for example) of α would be given by the relation $Z_\alpha(\rho,T) = Z_o(\rho h_{\alpha\alpha,o}, T/f_{\alpha\alpha,o})$. With the appropriate expression for the Helmholtz free energy, the thermodynamic properties of α are completely defined in terms of the properties of o.

It is a logical step to introduce shape factors into the viscosity and thermal conductivity expressions: for fluid α, therefore

$$\eta_\alpha(\rho,T) = \eta_o\,(\rho'_{\alpha,o}, T'_{\alpha,o})\, FH^\eta_{\alpha,o} \tag{10}$$

where

$$\rho'_{\alpha,o} = \rho h_{\alpha\alpha,o}; \quad T'_{\alpha,o} = T/f_{\alpha\alpha,o}; \quad FH^\eta_{\alpha,o} = \left(\frac{M_\alpha}{M_o}\right)^{1/2} h^{-2/3}_{\alpha\alpha,o}\, f^{1/2}_{\alpha\alpha,o} \tag{11}$$

Similarly,

$$\lambda_\alpha(\rho,T) = \lambda_o\,(\rho'_{\alpha,o}, T'_{\alpha,o})\, FH^\lambda_{\alpha,o} \tag{12}$$

where

$$FH^\lambda_{\alpha,o} = \left(\frac{M_o}{M_\alpha}\right)^{1/2} h^{-2/3}_{\alpha\alpha,o}\, f^{1/2}_{\alpha\alpha,o} \tag{13}$$

And for mixtures,

$$\eta_x(\rho,T) = \eta_o\,(\rho'_{x,o}, T'_{x,o})\, FH^\eta_{x,o} \tag{14}$$

$$\lambda_x(\rho,T) = \lambda_o\,(\rho'_{x,o}, T'_{x,o})\, FH^\lambda_{x,o} \tag{15}$$

For mixing rules for $h_{x,o}$ and $f_{x,o}$ we take

$$h_{x,o} = \sum_\alpha \sum_\beta x_\alpha x_\beta\, h_{\alpha\beta,o} \tag{16}$$

$$f_{x,o}\, h_{x,o} = \sum_\alpha \sum_\beta x_\alpha x_\beta\, f_{\alpha\beta,o}\, h_{\alpha\beta,o} \tag{17}$$

with

$$f_{\alpha\beta,o} = \xi_{\alpha\beta} \left(f_{\alpha\alpha,o} f_{\beta\beta,o}\right)^{1/2} \tag{18}$$

and

$$h_{\alpha\beta,o} = \psi_{\alpha\beta} \left[\frac{1}{2} h_{\alpha\alpha,o}^{1/3} + \frac{1}{2} h_{\beta\beta,o}^{1/3}\right]^3 \tag{19}$$

An evaluation of equations (10), (12), (14) and (15) is discussed in reference [1]. In particular we were interested if these equations could be used to <u>predict</u> the transport coefficients of α or x, given values for the reference fluid. Specifically, one might hope that equations could be used successfully if the shape factors, θ and ϕ, and the mixing interaction parameters, $\xi_{\alpha\beta}$ and $\psi_{\alpha\beta}$, were taken from a fit of thermodynamic (PVT) data. Unfortunately, the equations could not represent data satisfactorily if the above constraint was imposed.

We have, however, been able to propose a possible modification; we suggested that one should consider expressions of the form

$$\eta_\alpha(\rho,T) = \eta_o \left(\rho'_{\alpha,o}, T'_{\alpha,o}\right) FH^\eta_{\alpha,o} X^\eta_{\alpha,o} (\rho,T) \tag{20}$$

and

$$\lambda_\alpha(\rho,T) = \lambda_o \left(\rho'_{\alpha,o}, T'_{\alpha,o}\right) FH^\lambda_{\alpha,o} X^\lambda_{\alpha,o} (\rho,T) \tag{21}$$

with corresponding expression for the mixture. Note that equations (20) and (21) differ from those introduced earlier by the factor $X^\eta_{\alpha,o}$ or $X^\lambda_{\alpha,o}$. Based on how equations (20) and (21) represent experiment, it turns out that X should be unity if fluids α and o follow classical two-parameter corresponding states, as in the case of the rare gases and their mixtures [25], but should be a function of temperature and density otherwise.

No formal equation is available for X but a possible expression was determined in reference [1]. The expressions are based on a study of the Modified Enskog Theory. This theory has been discussed in detail in our

previous work [28]. Following the arguments that are given in full in reference [1], we obtained for the pure fluid (with corresponding expressions for the mixture)

$$X^{\eta}_{\alpha,o}(\rho,T) = Q_{\alpha,o}\, G^{\eta}_{\alpha,o} \quad : \quad X^{\lambda}_{\alpha,o}(\rho,T) = Q_{\alpha,o}\, G^{\lambda}_{\alpha,o} \tag{22}$$

$Q_{\alpha,o}$ is function of ρ and T defined as

$$Q_{\alpha,o} = [(b\rho)_{\alpha}/(b\rho)_{o}]^{[1 - 1/\exp (\rho^{c}/\rho)^{3}]} \tag{23}$$

where b is a term given by $b = B + TdB/dT$, with B the equilibrium secona virial coefficient. $G^{\eta}_{\alpha,o}$ and $G^{\lambda}_{\alpha,o}$ are ratios given, respectively, by $G^{\eta}_{\alpha,o} = [\,]^{\eta}_{\alpha}/[\,]^{\eta}_{o}$ and $[\,]^{\lambda}_{\alpha}/[\,]^{\lambda}_{o}$. The bracket expressions are [28]

$$\begin{aligned} [\,]^{\eta} &= [1/b\rho\chi + 0.8 + 0.761\, b\rho\chi] \\ [\,]^{\lambda} &= [1/b\rho\chi + 1.2 + 0.755\, b\rho\chi] \end{aligned} \tag{24}$$

with

$$b\rho\chi = \frac{1}{\rho R}\left(\frac{\partial P}{\partial T}\right)_{\rho} - 1 \tag{25}$$

for fluids α or o. R is the gas constant.

Notice that the calculation of the correction factors X^{η} and X^{λ} require only thermodynamic information for fluid α or x with respect to the reference fluid; for example, b_{α} [Equation (23)] can be obtained from the second virial coefficient of the reference fluid, B_o, according to the expression

$$b_{\alpha}(T) = h_{\alpha\alpha,o}\, B_o + T\, d\,\frac{(h_{\alpha\alpha,o}\, B_o)}{dT} \tag{26}$$

and similarly for the term $b\rho\chi$ [equation (25)].

3.1 Summary

To summarize the calculation procedure. To calculate the coefficients of a fluid, α, or mixture, x, one needs (a) the viscosity and thermal conductivity coefficients of a reference fluid, (b) the shape factors and, if necessary, the mixing parameters of the fluid with respect to the reference fluid; these quantities to be obtained from a fit of thermodynamic data. The viscosity and thermal conductivity of α or x follow from the equations

$$\eta_\alpha(\rho,T) = \eta_o\,(\rho'_{\alpha,o}, T'_{\alpha,o})\; FH^{\eta}_{\alpha,o}\; X^{\eta}_{\alpha,o} \tag{20}$$

$$\lambda_\alpha(\rho,T) = \lambda_o\,(\rho_{\alpha,o}, T'_{\alpha,o})\; FH^{\lambda}_{\alpha,o}\; X^{\lambda}_{\alpha,o} \tag{21}$$

$$\eta_x(\rho,T) = \eta_o(\rho'_{x,o}, T'_{x,o})\; FH^{\eta}_{x,o}\; X^{\eta}_{x,o} \tag{27}$$

$$\lambda_x(\rho,T) = \lambda_o\,(\rho'_{x,o}, T'_{x,o})\; FH^{\lambda}_{x,o}\; X^{\lambda}_{x,o} \tag{28}$$

In this work α is, of course, nitrous oxide. Methane was chosen as the reference fluid and numerical values of the transport coefficients were those of the correlation of Hanley, Haynes and McCarty [24]. The equation of state for methane used here is due to Goodwin [29].

Shape factors for nitrous oxide with respect to methane, equation (8), were obtained by analyzing the PVT data of Couch, Kobe and Hirth [30]. The procedure is due to McCarty [31] and will not be described here.

3.2 Kinetic Theory

For consistency, the transport coefficients of nitrous oxide for all pressures and temperatures will be calculated by the method summarized in section 3.1. However, alternative approachs are possible for the dilute gas since some data are available. In previous work on the dilute gas [32-34], we

have used an empirical fit of data and/or calculated values via statistical mechanics and kinetic theory. This latter approach has several advantages, one of which is that statistical mechanics and kinetic theory allow an assessment to be made of systematic error by comparing independently measured properties through the pair potential function. For example, in references [32-34], we showed the transport properties of the rare gases, and oxygen and nitrogen were consistent with their respective second virial coefficients. As a matter of interest, nitrous oxide is briefly discussed along these lines in the Appendix.

3.3 The Behavior of the Thermal Conductivity Coefficient in the Critical Region

It is now well known that the thermal conductivity behaves anomalously in the vicinity of the critical point: in fact the coefficient will approach infinity as the density and temperature approach their critical values. An account of this phenomenon is given in reference [35], and it is considered in our previous data correlations of argon, oxygen, nitrogen and methane [24]. Undoubtedly, nitrous oxide will also display the anomaly.

The anomaly can be calculated directly and is discussed in reference [35] but it is included indirectly in our corresponding states procedure as follows.

The thermal conductivity is given by equation (21)

$$\lambda_\alpha(\rho,T) = \lambda_o\,(\rho_{\alpha,o},\,T_{\alpha,o})\,FH^\lambda_{\alpha,o}\,X^\lambda_{\alpha,o}\,(\rho,T) \tag{21}$$

where $\alpha \equiv N_2O$ and $o \equiv CH_4$, but λ_o can be separated into two terms, the conductivity in the absence of a critical point anomaly, λ'_o, and the anomaly itself, λ^c_o:

$$\lambda_o = \lambda'_o + \lambda^c_o \tag{29}$$

Hence

$$\lambda_\alpha = \lambda'_o\,FH^\lambda_{\alpha,o}\,X^\lambda_{\alpha,o} + \lambda^c_o\,FH^\lambda_{\alpha,o}\,X^\lambda_{\alpha,o} \tag{30}$$

Since we have incorporated λ_o^c in the methane correlation, λ_α will have an equivalent contribution.

4. COMPARISONS WITH DATA

Comparisons between our calculated values of the transport properties of nitrous oxide and data are restricted to the dilute gas region, and to one data set for the thermal conductivity [19]. First the dilute gas.

We attempted to assess the accuracy of the dilute gas viscosity data using the arguments discussed in reference [24]. Data from references [6] and [7] were selected as the most reliable with an estimated accuracy of $\pm$ 3%.

The dilute gas thermal conductivity data were also evaluated as far as possible. Data from references [10], [14] and [18] were selected as the more reliable with an estimated accuracy of $\pm$ 6%.

Following the procedure of our previous work [24], the selected viscosity and thermal conductivity data were fitted to an empirical function for computation convenience

$$\eta^o = GV(1)T^{-1} + GV(2)T^{-2/3} + GV(3)T^{-1/3} + GV(4) + GV(5)T^{1/3} + GV(6)T^{2/3} + GV(7)T + GV(8)T^{4/3} + GV(9)T^{5/3} \quad , \tag{31}$$

and similarly for λ^o, but with coefficients GT(i)(i = 1...9) replacing GV(i) in equation (31). η^o and λ^o refer to the dilute gas viscosity and thermal conductivity coefficients, respectively. Values of GV and GT are listed in table 1.

Table 1. Values of the coefficients of equation (31) for the dilute gas viscosity, η^{o}, and the dilute gas thermal conductivity, λ^{o}. Units: temperature in K, η^{o} in μg/(cm•s) and λ^{o} in mW/(m•K).

GV(1)	=	.2546211337E+07
GV(2)	=	-.1670382040E+07
GV(3)	=	.2898185505E+06
GV(4)	=	.3474760268E+05
GV(5)	=	-.1674096936E+05
GV(6)	=	.1445438546E+04
GV(7)	=	.8767956930E+02
GV(8)	=	-.1932828150E+02
GV(9)	=	.7959594290E+00

GT(1)	=	-.1550251226E+07
GT(2)	=	.9682908726E+06
GT(3)	=	-.2120883669E+06
GT(4)	=	.1779303821E+05
GT(5)	=	-.9793550977E+03
GT(6)	=	.3480491811E+03
GT(7)	=	-.6424000898E+02
GT(8)	=	.4582750314E+01
GT(9)	=	-.1120206739E+00

Figure 1 displays a deviation plot between the experimental data fitted to equation (31), and our estimates from equations (20) and (21), with the pressure set at one atmosphere. Our representation of the dilute gas viscosity coefficient can be considered satisfactory, the thermal conductivity less so. for both coefficients systematic differences are observed but it is not clear whether they are caused by errors in the procedure, or are due to errors in the data. A possible reason for the deviations in the thermal conductivity is that our method does not take into account correctly the contribution of the internal degrees of freedom of nitrous oxide. This problem is under further investigation.

We next compared our predicted conductivities for nitrous oxide with the dense gas and liquid data of reference [19]. The result is shown in figure 2. It is seen that the calculated values are within about 5%, or less, of the measured values.

5. TABLES

Tables of values for the viscosity and thermal conductivity coefficients of nitrous oxide were generated from equations (20) and (21). Tables 2 and 3 give the results in the SI system of units, tables 4 and 5 in engineering units. For convenience, saturated liquid values are listed separately as table 6*.

5.1 Assessment of Accuracy

An estimation of the accuracy of the tabular values is clearly difficult and has to be based mainly on how well the prediction method can represent other fluids for which reliable data are available. For nitrogen, ethane, propane, butane and carbon dioxide, and their mixtures, we were generally able to predict the coefficients to within about 6% using methane as the reference fluid. Here we have represented the dilute gas viscosity data to 3% and the dilute gas thermal conductivity data to 10%. The dense gas thermal

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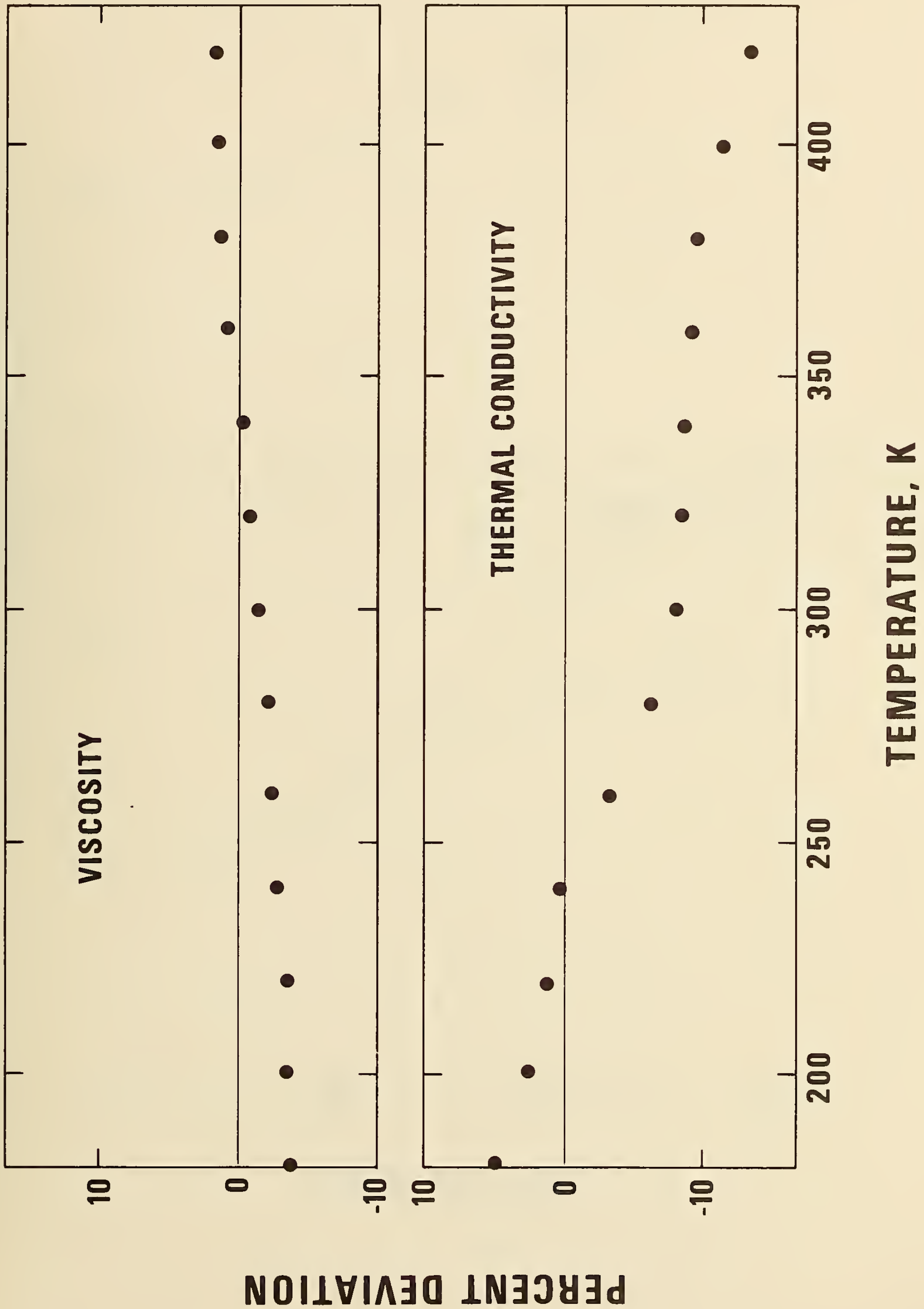
* The number of significant figures for an entry are more than the accuracy of the calculations warrant (see Section 5.1). Extra figures are included to facilitate interpolation if required.

conductivity measurements of reference [19] have been represented to within 6%. Based on the above two factors, and our experience in evaluating data for fluids similar to nitrous oxide, we estimate the viscosity to be accurate to ± 6% and the thermal conductivity to be accurate to ± 8%. In the critical region this latter figure should be increased to ± 20%. As in our previous work, these assessments refer to an accuracy estimation on a 2σ basis.

Figure 1. Top curve: 1 atm viscosity percent deviation plot between values predicted from equation (20) and the correlation equation (31). Percent deviation is defined as η[eq. (20)] - η[eq. (31)]*100.0/η[eq. (31)]. Bottom curve: 1 atm thermal conductivity deviations between equation (21) and equation (31).



VISCOSITY
THERMAL CONDUCTIVITY
PERCENT DEVIATION
TEMPERATURE, K
10
0
-10
200
250
300
350
400

Figure 2. Dense gas and liquid isotherms for the thermal conductivity coefficient calculated from equation (21) (curves) compared with the data of reference [19] (open and filled circles).

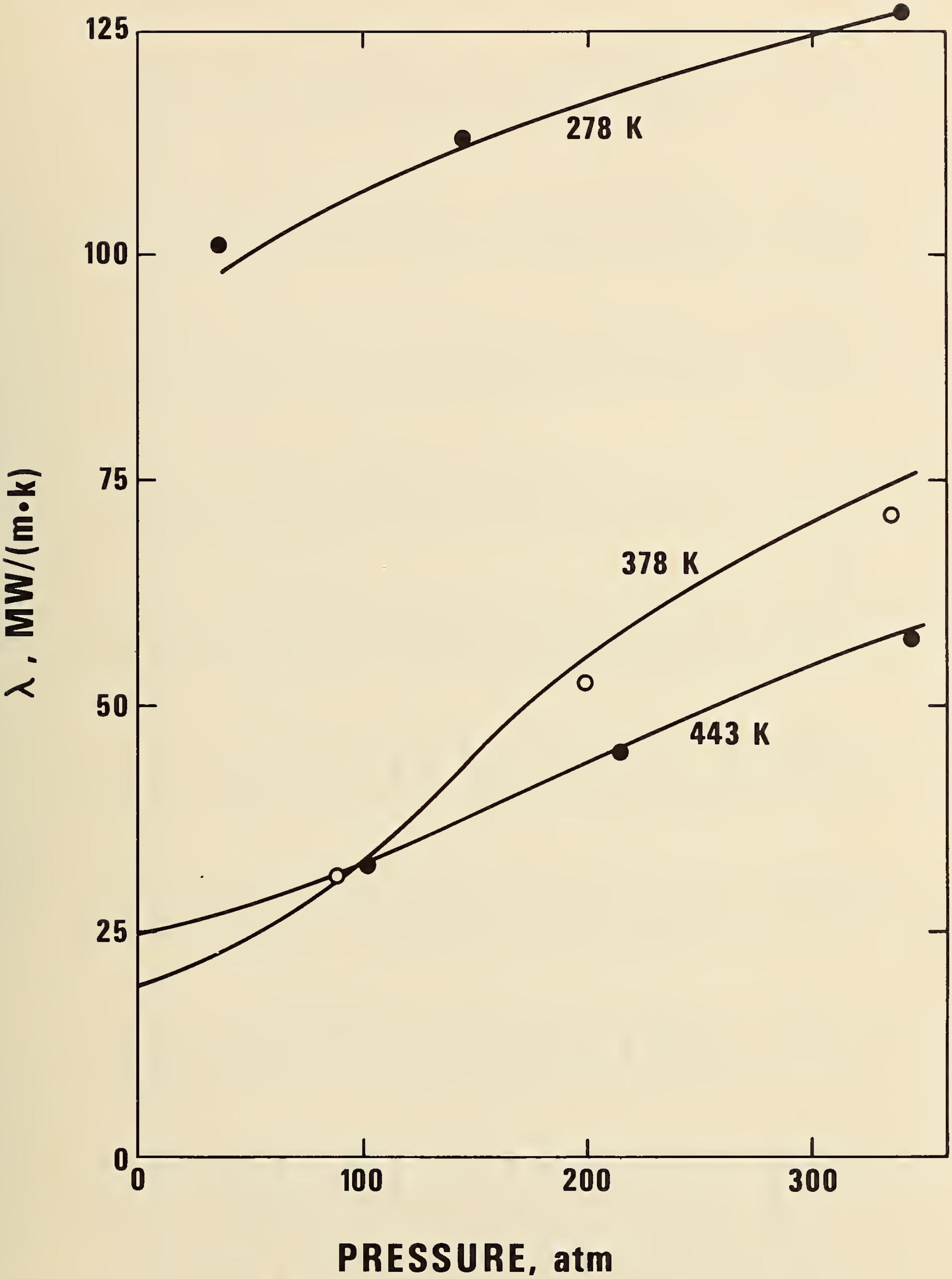

125
100
75
50
25
0
0
100
200
300
278 K
378 K
443 K
λ , MW/(m•k)
PRESSURE, atm

Table 2. The viscosity of nitrous oxide. Units μg/(cm·s).

T, K	P, MPa .1	1.0	2.0	3.0	4.0	5.0	10.0	15.0	20.0	25.0
180.	4068.6									
220.	104.8	2225.4	2243.7	2261.9	2280.0	2298.0	2386.4	2472.7	2557.2	2640.2
260.	125.1	131.9	141.9	1333.2	1353.1	1372.4	1462.1	1543.6	1619.2	1690.6
300.	145.6	150.8	157.9	167.0	178.9	196.2	861.0	973.1	1069.9	1147.7
340.	166.1	170.4	175.9	182.4	190.1	199.3	294.9	545.8	688.3	784.9
380.	186.5	190.1	194.7	199.9	205.8	212.5	261.2	345.4	460.6	559.0
420.	206.6	209.9	213.9	218.3	223.2	228.6	264.0	314.5	377.7	443.4
460.	226.5	229.4	233.0	237.0	241.2	245.9	274.6	312.5	355.2	403.7
500.	245.9	248.7	252.1	255.6	259.5	263.6	288.2	318.9	353.5	383.2
540.	265.1	267.8	270.9	274.2	277.8	281.5	303.3	329.5	359.4	387.0
580.	283.9	286.5	289.5	292.7	296.0	299.5	319.4	342.5	368.3	393.6
620.	302.3	304.9	307.9	310.9	314.2	317.5	336.0	357.1	380.0	404.2
660.	320.5	323.1	326.0	329.1	332.2	335.5	353.2	372.7	393.6	415.4
700.	338.3	341.0	344.0	347.1	350.3	353.5	370.8	389.3	408.7	428.8
740.	355.8	358.7	361.9	365.1	368.4	371.7	388.9	406.8	425.3	444.1
780.	373.0	376.2	379.7	383.2	386.7	390.2	407.7	425.5	443.3	461.3
820.	390.1	393.7	397.6	401.5	405.3	409.1	427.5	445.5	463.1	480.5
860.	406.9	411.3	415.9	420.4	424.8	429.0	449.0	467.6	485.2	502.3
900.	423.5	429.2	435.1	440.7	446.0	451.0	473.4	493.0	510.9	527.8

Table 3. The thermal conductivity of nitrous oxide. Units mW/(m•s).

	P, MPa									
T, K	.1	1.0	2.0	3.0	4.0	5.0	10.0	15.0	20.0	25.0
180.	202.24									
220.	11.20	153.91	154.68	155.43	156.18	156.93	160.54	164.02	167.37	170.62
260.	13.35	14.98	16.95	114.40	115.56	116.68	121.81	126.38	130.54	134.41
300.	15.55	16.89	18.32	20.01	22.30	26.15	95.69	93.35	99.55	104.77
340.	17.82	18.96	20.10	21.31	22.68	24.29	42.74	67.61	75.75	81.35
380.	20.21	21.22	22.18	23.14	24.15	25.24	32.49	43.45	55.27	63.82
420.	22.76	23.68	24.53	25.35	26.20	27.06	32.02	38.14	44.97	52.05
460.	25.50	26.35	27.12	27.87	28.61	29.37	33.43	38.08	42.80	47.79
500.	28.45	29.24	29.96	30.65	31.33	32.01	35.57	39.44	43.40	47.03
540.	31.60	32.36	33.04	33.68	34.32	34.95	38.16	41.57	45.09	48.13
580.	34.97	35.70	36.35	36.97	37.57	38.17	41.17	44.25	47.38	50.26
620.	38.55	39.26	39.90	40.50	41.08	41.66	44.51	47.38	50.24	53.05
660.	42.33	43.04	43.67	44.26	44.84	45.41	48.18	50.90	53.59	56.22
700.	46.31	47.02	47.66	48.26	48.84	49.41	52.15	54.80	57.38	59.86
740.	50.47	51.20	51.86	52.48	53.08	53.67	56.44	59.07	61.58	63.98
780.	54.80	55.57	56.28	56.94	57.57	58.19	61.07	63.73	66.22	68.57
820.	59.29	60.13	60.91	61.64	62.34	63.00	66.07	68.83	71.35	73.69
860.	63.93	64.89	65.80	66.64	67.43	68.18	71.56	74.47	77.07	79.43
900.	68.71	69.90	71.02	72.04	73.00	73.89	77.74	80.89	83.60	86.00

Table 4. The viscosity coefficient of nitrous oxide. Pressure in 10^{-2} psi [i.e., pressure in psi is obtained by multiplying by 100.0], temperature in degrees Rankine, viscosity coefficient in 10^{7} lb/(ft.s) [i.e., to obtain η in lb/(ft.s), multiply the entries by 10^{-7}].

Table 4.

	P, 10^{-2} psi									
T, ^{o}R	.2	1.0	2.0	4.0	6.0	8.0	10.0	11.0	12.0	13.0
330.	2581.7	2591.1	2602.2	2624.3	2646.5	2668.7	2690.9	2702.0		
350.	61.9	2163.1	2173.0	2192.7	2212.5	2232.1	2251.8	2261.6	2271.4	2281.2
370.	65.6	1829.4	1838.5	1856.6	1874.6	1892.6	1910.5	1919.4	1928.3	1937.2
390.	69.3	1561.9	1570.5	1587.6	1604.6	1621.4	1638.2	1646.5	1654.8	1663.1
410.	73.1	76.5	1350.2	1366.9	1383.4	1399.6	1415.7	1423.7	1431.7	1439.6
430.	76.9	80.1	1164.5	1181.3	1197.8	1214.0	1229.9	1237.8	1245.6	1253.4
450.	80.6	83.7	88.0	1021.2	1038.4	1055.0	1071.3	1079.3	1087.2	1095.1
470.	84.4	87.3	91.2	878.9	897.6	915.5	932.7	941.1	949.4	957.5
490.	88.3	90.9	94.5	104.6	768.8	789.2	808.4	817.6	826.6	835.4
510.	92.1	94.6	97.9	106.8	639.4	666.2	690.2	701.4	712.3	722.7
530.	95.9	98.2	101.3	109.2	121.2	536.9	571.4	586.1	599.8	612.7
550.	99.7	101.9	104.8	112.0	122.1	138.2	428.0	458.8	481.9	501.2
570.	103.6	105.6	108.3	114.9	123.7	136.3	157.2	177.2	248.6	354.5
590.	107.4	109.4	111.9	117.9	125.8	136.4	151.4	161.8	176.0	197.0
610.	111.2	113.1	115.5	121.1	128.3	137.4	149.5	157.2	166.4	177.7
630.	115.1	116.8	119.1	124.4	130.9	139.1	149.4	155.6	162.7	171.0
650.	118.9	120.6	122.7	127.7	133.8	141.2	150.2	155.5	161.4	168.0
670.	122.7	124.3	126.3	131.1	136.7	143.5	151.7	156.3	161.4	167.0
690.	126.4	128.0	130.0	134.5	139.8	146.1	153.5	157.7	162.2	167.1
710.	130.2	131.7	133.6	137.9	143.0	148.9	155.7	159.5	163.6	168.0
730.	134.0	135.4	137.3	141.4	146.2	151.8	158.1	161.6	165.4	169.3
750.	137.7	139.2	140.9	144.9	149.5	154.7	160.7	164.0	167.4	171.1
770.	141.5	142.8	144.6	148.4	152.8	157.8	163.4	166.5	169.7	173.1

Table 4. (Continued)

T, °R	P, 10^{-2} psi 14.0	15.0	16.0	17.0	18.0	19.0	20.0	25.0	30.0	35.0
330.										
350.	2291.0	2300.8	2310.6	2320.4	2330.2	2340.0	2349.7	2398.5	2447.1	2495.6
370.	1946.1	1954.9	1963.8	1972.6	1981.4	1990.2	1999.0	2042.8	2086.3	2129.5
390.	1671.3	1679.6	1687.8	1696.0	1704.1	1712.3	1720.4	1760.7	1800.5	1839.8
410.	1447.5	1455.3	1463.1	1470.9	1478.6	1486.3	1494.0	1531.9	1569.1	1605.8
430.	1261.1	1268.8	1276.4	1283.9	1291.4	1298.9	1306.3	1342.8	1378.4	1413.1
450.	1102.8	1110.5	1118.1	1125.6	1133.1	1140.5	1147.8	1183.7	1218.4	1252.0
470.	965.6	973.5	981.3	989.0	996.6	1004.2	1011.6	1047.7	1082.1	1115.1
490.	844.0	852.4	860.7	868.8	876.8	884.7	892.4	929.5	964.3	997.3
510.	732.8	742.6	752.0	760.8	769.5	777.9	786.2	825.2	861.1	894.6
530.	624.8	636.3	647.3	657.9	668.0	677.8	687.4	731.2	769.6	804.1
550.	518.1	533.3	547.3	560.3	572.4	583.9	594.9	643.5	685.2	722.6
570.	395.1	422.5	444.4	462.8	479.1	493.8	507.4	563.6	609.0	648.3
590.	232.6	281.4	324.3	356.8	382.4	403.5	421.7	490.0	540.2	581.9
610.	191.7	210.2	234.2	262.3	290.7	316.8	339.8	422.4	478.4	522.9
630.	180.5	191.4	204.3	219.8	237.7	257.4	277.6	363.3	423.7	470.6
650.	175.5	183.8	192.8	203.0	214.6	227.6	241.8	316.7	377.4	425.4
670.	173.2	180.0	187.4	195.1	203.6	213.0	223.2	283.3	340.3	387.5
690.	172.4	178.2	184.4	191.2	197.9	205.3	213.2	260.7	311.8	356.7
710.	172.7	177.7	183.1	188.9	195.0	201.1	207.6	246.0	290.3	332.1
730.	173.6	178.1	182.9	187.9	193.3	199.0	204.5	236.5	274.5	312.8
750.	174.9	179.0	183.4	187.9	192.7	197.7	203.0	230.4	263.1	297.6
770.	176.7	180.4	184.4	188.5	192.8	197.4	202.1	226.5	254.9	285.8

Table 4. (Continued)

	P, 10^{-2} psi									
T, °R	.2	1.0	2.0	4.0	6.0	8.0	10.0	11.0	12.0	13.0
800.	147.0	148.4	150.0	153.7	157.8	162.5	167.7	170.5	173.4	176.5
850.	156.2	157.5	159.0	162.4	166.2	170.5	175.1	177.6	180.2	182.9
900.	165.3	166.5	168.0	171.2	174.7	178.6	182.9	185.1	187.5	189.9
950.	174.2	175.4	176.8	179.9	183.3	186.9	190.8	192.9	195.0	197.2
1000.	183.1	184.2	185.6	188.6	191.8	195.2	198.9	200.8	202.8	204.8
1050.	191.8	192.9	194.3	197.2	200.2	203.5	207.0	208.8	210.7	212.6
1100.	200.4	201.6	202.9	205.7	208.7	211.9	215.2	216.9	218.7	220.5
1150.	208.9	210.1	211.4	214.2	217.1	220.2	223.5	225.1	226.8	228.6
1200.	217.4	218.5	219.9	222.6	225.6	228.6	231.8	233.4	235.0	236.7
1250.	225.7	226.8	228.2	231.1	234.0	237.0	240.2	241.7	243.4	245.0
1300.	233.9	235.1	236.5	239.4	242.4	245.5	248.6	250.2	251.8	253.4
1350.	242.0	243.3	244.8	247.8	250.9	254.0	257.2	258.8	260.4	262.0
1400.	250.0	251.4	253.0	256.2	259.5	262.7	265.9	267.5	269.2	270.8
1450.	258.0	259.5	261.3	264.7	268.1	271.5	274.9	276.5	278.2	279.9
1500.	265.9	267.6	269.5	273.3	277.0	280.6	284.2	285.9	287.7	289.4
1550.	273.7	275.7	277.9	282.1	286.2	290.1	293.9	295.8	297.6	299.5
1600.	281.5	283.8	286.4	291.4	296.0	300.4	304.5	306.5	308.5	310.4

Table 4. (Continued)

T, °R	P, 10^{-2} psi									
	14.0	15.0	16.0	17.0	18.0	19.0	20.0	25.0	30.0	35.0
800.	179.7	183.1	186.6	190.3	194.1	198.0	202.2	223.5	247.0	273.1
850.	185.7	188.6	191.6	194.7	197.9	201.2	204.6	223.1	241.2	261.3
900.	192.4	194.9	197.6	200.3	203.1	206.0	208.9	224.7	240.5	256.6
950.	199.5	201.8	204.2	206.6	209.1	211.7	214.3	228.2	243.0	256.1
1000.	206.9	209.0	211.2	213.4	215.7	218.1	220.4	232.9	246.2	258.4
1050.	214.5	216.5	218.6	220.6	222.7	224.9	227.0	238.4	250.5	262.6
1100.	222.3	224.2	226.1	228.1	230.0	232.0	234.1	244.6	255.7	267.2
1150.	230.3	232.1	233.9	235.7	237.6	239.5	241.4	251.3	261.6	272.2
1200.	238.4	240.1	241.9	243.6	245.4	247.2	249.0	258.4	268.1	278.0
1250.	246.6	248.3	250.0	251.7	253.4	255.2	256.9	265.8	275.0	284.4
1300.	255.0	256.7	258.3	260.0	261.7	263.4	265.1	273.7	282.5	291.4
1350.	263.6	265.2	266.9	268.5	270.2	271.8	273.5	281.9	290.4	299.0
1400.	272.4	274.1	275.7	277.3	279.0	280.6	282.3	290.6	298.9	307.2
1450.	281.5	283.2	284.9	286.5	288.2	289.8	291.5	299.7	307.9	316.0
1500.	291.1	292.8	294.5	296.2	297.9	299.5	301.2	309.4	317.5	325.5
1550.	301.3	303.0	304.8	306.5	308.3	310.0	311.7	320.0	328.1	336.0
1600.	312.3	314.2	316.1	317.9	319.7	321.4	323.2	331.7	339.8	347.6

Table 5. The thermal conductivity coefficient of nitrous oxide. Pressure in 10^{-2} psi [i.e., to obtain the pressure in psi multiply by 100.0], temperature in degrees Rankine, thermal conductivity in 10^{3} BTU/(ft. hr. °R) [i.e., to obtain λ in BTU/(ft. hr. °R), multiply the entries by 10^{-3}].

Table 5.

T, ^{o}R	P, 10^{-2} psi .2	1.0	2.0	4.0	6.0	8.0	10.0	11.0	12.0	13.0
330.	114.26	114.48	114.74	115.25	115.76	116.27	116.78	117.03		
350.	5.70	106.09	106.35	106.88	107.41	107.93	108.45	108.71	108.97	109.23
370.	6.04	98.30	98.58	99.13	99.68	100.23	100.77	101.04	101.31	101.58
390.	6.38	90.98	91.28	91.87	92.45	93.03	93.60	93.89	94.17	94.45
410.	6.72	7.45	84.32	84.96	85.60	86.22	86.83	87.13	87.44	87.73
430.	7.07	7.76	77.60	78.31	79.01	79.70	80.37	80.70	81.02	81.35
450.	7.41	8.07	8.83	71.81	72.61	73.38	74.13	74.49	74.86	75.21
470.	7.76	8.38	9.08	65.32	66.27	67.16	68.02	68.44	68.85	69.25
490.	8.11	8.70	9.35	11.01	59.82	60.92	61.95	62.45	62.92	63.39
510.	8.46	9.02	9.63	11.09	52.75	54.27	55.63	56.27	56.88	57.47
530.	8.81	9.35	9.92	11.23	13.25	47.31	49.10	49.89	50.65	51.37
550.	9.17	9.68	10.22	11.41	13.06	16.19	43.11	44.04	44.92	45.74
570.	9.53	10.02	10.53	11.62	13.02	15.21	19.64	24.58	39.95	40.93
590.	9.90	10.37	10.85	11.86	13.09	14.79	17.49	19.54	22.38	26.53
610.	10.27	10.72	11.18	12.12	13.21	14.62	16.57	17.88	19.48	21.43
630.	10.64	11.08	11.52	12.40	13.39	14.59	16.13	17.08	18.18	19.45
650.	11.03	11.45	11.87	12.70	13.61	14.66	15.93	16.68	17.52	18.45
670.	11.41	11.82	12.22	13.01	13.86	14.80	15.90	16.52	17.19	17.92
690.	11.81	12.20	12.59	13.35	14.13	15.00	15.97	16.50	17.07	17.68
710.	12.21	12.60	12.97	13.69	14.44	15.24	16.12	16.59	17.09	17.61
730.	12.62	13.00	13.36	14.05	14.76	15.51	16.32	16.75	17.20	17.67
750.	13.04	13.40	13.76	14.43	15.11	15.82	16.57	16.97	17.38	17.81
770.	13.46	13.82	14.17	14.82	15.47	16.15	16.86	17.23	17.61	18.01

Table 5. (Continued)

	$p, 10^{-2}$ psi									
T, °R	14.0	15.0	16.0	17.0	18.0	19.0	20.0	25.0	30.0	35.0
330.										
350.	109.48	109.74	110.00	110.25	110.51	110.76	111.02	112.27	113.52	114.75
370.	101.84	102.11	102.37	102.64	102.90	103.16	103.42	104.71	105.98	107.23
390.	94.73	95.01	95.28	95.56	95.83	96.10	96.37	97.71	99.02	100.31
410.	88.03	88.33	88.62	88.91	89.20	89.49	89.77	91.17	92.54	93.87
430.	81.67	81.99	82.30	82.61	82.92	83.23	83.53	85.02	86.45	87.84
450.	75.56	75.91	76.26	76.59	76.93	77.26	77.59	79.19	80.71	82.17
470.	69.65	70.04	70.42	70.80	71.17	71.53	71.89	73.63	75.26	76.81
490.	63.85	64.29	64.73	65.15	65.57	65.98	66.38	68.30	70.07	71.73
510.	58.04	58.60	59.12	59.61	60.09	60.56	61.02	63.16	65.10	66.90
530.	52.05	52.70	53.33	53.94	54.52	55.08	55.63	58.16	60.35	62.30
550.	46.52	47.26	47.96	48.63	49.27	49.90	50.50	53.25	55.69	57.88
570.	41.84	42.68	43.45	44.17	44.84	45.48	46.09	48.90	51.40	53.68
590.	31.80	35.87	38.20	39.66	40.72	41.59	42.33	45.27	47.73	49.97
610.	23.84	26.65	29.61	32.31	34.52	36.28	37.68	41.93	44.58	46.80
630.	20.91	22.56	24.40	26.36	28.36	30.28	32.03	38.09	41.50	43.94
650.	19.49	20.62	21.85	23.18	24.59	26.06	27.53	33.94	38.15	41.06
670.	18.72	19.59	20.51	21.47	22.50	23.57	24.69	30.33	34.82	38.12
690.	18.33	19.02	19.76	20.54	21.32	22.14	23.00	27.63	31.95	35.37
710.	18.17	18.75	19.36	20.01	20.68	21.34	22.03	25.80	29.68	33.04
730.	18.15	18.66	19.19	19.75	20.32	20.92	21.49	24.62	28.01	31.18
750.	18.25	18.70	19.18	19.67	20.17	20.69	21.23	23.90	26.84	29.76
770.	18.41	18.83	19.26	19.70	20.16	20.63	21.11	23.48	26.06	28.71

Table 5. (Continued)

	P, 10^{-2} psi									
T, ^{o}R	.2	1.0	2.0	4.0	6.0	8.0	10.0	11.0	12.0	13.0
800.	14.12	14.47	14.80	15.42	16.04	16.68	17.34	17.68	18.03	18.39
850.	15.25	15.59	15.90	16.49	17.06	17.65	18.25	18.55	18.87	19.18
900.	16.45	16.77	17.07	17.62	18.17	18.71	19.27	19.55	19.83	20.12
950.	17.70	18.01	18.30	18.83	19.35	19.86	20.38	20.65	20.91	21.18
1000.	19.02	19.31	19.59	20.11	20.60	21.10	21.59	21.84	22.09	22.34
1050.	20.39	20.68	20.95	21.45	21.93	22.41	22.88	23.12	23.36	23.60
1100.	21.82	22.11	22.37	22.87	23.33	23.80	24.26	24.48	24.71	24.94
1150.	23.31	23.59	23.86	24.34	24.81	25.26	25.71	25.93	26.16	26.38
1200.	24.85	25.13	25.40	25.89	26.35	26.80	27.24	27.46	27.68	27.90
1250.	26.45	26.73	27.00	27.49	27.95	28.40	28.85	29.07	29.28	29.50
1300.	28.10	28.39	28.66	29.16	29.63	30.09	30.53	30.75	30.97	31.19
1350.	29.80	30.09	30.37	30.89	31.37	31.84	32.29	32.52	32.74	32.96
1400.	31.55	31.85	32.14	32.68	33.19	33.67	34.14	34.37	34.60	34.82
1450.	33.34	33.65	33.97	34.54	35.08	35.59	36.08	36.32	36.55	36.79
1500.	35.17	35.51	35.85	36.48	37.05	37.60	38.12	38.37	38.62	38.87
1550.	37.04	37.42	37.80	38.50	39.13	39.73	40.29	40.56	40.83	41.09
1600.	38.95	39.39	39.83	40.62	41.34	42.01	42.63	42.93	43.21	43.49

Table 5. (Continued)

	P, 10^{-2} psi									
T, ^{o}R	14.0	15.0	16.0	17.0	18.0	19.0	20.0	25.0	30.0	35.0
800.	18.76	19.13	19.52	19.91	20.31	20.72	21.14	23.23	25.39	27.67
850.	19.51	19.84	20.17	20.51	20.85	21.20	21.56	23.40	25.09	26.89
900.	20.42	20.71	21.01	21.31	21.62	21.93	22.24	23.85	25.37	26.84
950.	21.45	21.72	22.00	22.27	22.55	22.83	23.12	24.56	26.02	27.25
1000.	22.59	22.85	23.10	23.36	23.62	23.88	24.14	25.47	26.81	27.97
1050.	23.84	24.08	24.32	24.56	24.81	25.05	25.29	26.53	27.77	28.95
1100.	25.17	25.41	25.64	25.87	26.10	26.33	26.56	27.73	28.89	30.04
1150.	26.60	26.82	27.05	27.27	27.49	27.72	27.94	29.05	30.15	31.24
1200.	28.12	28.33	28.55	28.77	28.98	29.20	29.42	30.49	31.54	32.58
1250.	29.72	29.93	30.14	30.36	30.57	30.78	30.99	32.03	33.06	34.05
1300.	31.40	31.62	31.83	32.04	32.25	32.46	32.67	33.69	34.69	35.66
1350.	33.18	33.39	33.61	33.82	34.03	34.24	34.44	35.46	36.44	37.39
1400.	35.04	35.26	35.48	35.70	35.91	36.12	36.33	37.35	38.32	39.26
1450.	37.02	37.24	37.46	37.68	37.90	38.12	38.33	39.36	40.34	41.27
1500.	39.11	39.34	39.57	39.80	40.03	40.25	40.47	41.52	42.50	43.44
1550.	41.34	41.59	41.83	42.07	42.31	42.54	42.76	43.85	44.85	45.79
1600.	43.77	44.03	44.29	44.55	44.79	45.04	45.27	46.40	47.43	48.38

Table 6. Saturated Liquid Transport Coefficients for N_2O

T °F	T °R	η lb-mass/ft·s	λ BTU/hr·ft·°F
-127.03	332.64	.25188E-03	.11312E+00
- 99.99	359.68	.19866E-03	.10210E+00
- 50.0	409.66	.13464E-03	.84157E-01
- 40.0	419.67	.12516E-03	.80840E-01
- 22.0	437.67	.10998E-03	.75034E-01
- 4.0	455.67	.96711E-04	.69392E-01
5.0	464.67	.90656E-04	.66617E-01
14.0	473.67	.84921E-04	.63863E-01
23.0	482.67	.79464E-04	.61126E-01
32.0	491.67	.74250E-04	.58405E-01
41.0	500.67	.68980E-04	.55536E-01
50.0	509.67	.63901E-04	.52725E-01
59.0	518.67	.58956E-04	.50018E-01
68.0	527.67	.54078E-04	.47495E-01
77.0	536.67	.49158E-04	.45266E-01
86.0	545.67	.44106E-04	.43498E-01
95.9	555.57	.38150E-04	.42357E-01

6. MIXTURES

Equations (27) and (28) were used to generate tables for two mixtures of nitrous oxide with carbon dioxide: compositions CO_2 (12%) - N_2O (88%) and CO_2 (6%) - N_2O (0.94%), respectively. The results are tables 7-10. Since carbon dioxide is so similar to nitrous oxide, our accuracy assessments for pure nitrous oxide are probably valid for mixtures. No data are available for comparisons.

7. CONCLUSION

We have predicted the transport coefficients of nitrous oxide, and of nitrous oxide/carbon dioxide mixtures using a significant modification of the corresponding states procedure. Tabular values have been listed. Data available for comparisons are scanty. More, and more reliable, data will be required if the accuracy of the tables is to be improved.

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Table 7. The viscosity of a mixture of 12% CO_2 and 88% N_2O.

Units as for pure N_2O.

T, °R	P, 10^{-2} psi .2	1.0	2.0	4.0	6.0	8.0	10.0	11.0	12.0	13.0
330.	2527.1	2536.5	2547.6	2569.6	2591.7	2613.8	2635.9	2647.0	2658.1	2669.1
350.	62.1	2115.7	2125.5	2145.3	2164.9	2184.6	2204.2	2214.0	2223.8	2233.6
370.	65.8	1787.2	1796.3	1814.5	1832.5	1850.5	1868.4	1877.4	1886.3	1895.2
390.	69.6	1523.6	1532.3	1549.5	1566.6	1583.5	1600.4	1608.7	1617.1	1625.4
410.	73.4	76.9	1314.9	1331.8	1348.4	1364.9	1381.1	1389.2	1397.2	1405.2
430.	77.2	80.5	1131.1	1148.2	1165.1	1181.5	1197.7	1205.7	1213.7	1221.5
450.	81.0	84.1	88.4	989.4	1007.0	1024.1	1040.8	1049.0	1057.1	1065.1
470.	84.9	87.7	91.7	847.2	866.7	885.4	903.2	911.9	920.4	928.8
490.	88.7	91.4	95.0	105.1	736.8	758.8	779.0	788.7	798.1	807.3
510.	92.6	95.1	98.4	107.2	601.9	632.2	658.5	670.7	682.2	693.4
530.	96.4	98.8	101.9	109.8	121.5	492.1	534.9	552.0	567.5	581.7
550.	100.3	102.5	105.4	112.5	122.5	137.9	174.0	405.6	439.5	464.2
570.	104.2	106.2	108.9	115.5	124.3	136.5	155.6	171.3	200.4	276.2
590.	108.0	110.0	112.5	118.6	126.4	136.8	151.1	160.7	173.1	189.6
610.	111.9	113.8	116.2	121.8	128.9	138.0	149.8	157.1	165.7	176.0
630.	115.8	117.5	119.8	125.1	131.7	139.8	149.9	155.9	162.7	170.5
650.	119.6	121.3	123.5	128.5	134.6	141.9	150.9	156.1	161.8	168.2
670.	123.5	125.1	127.2	131.9	137.6	144.4	152.4	157.0	162.0	167.5
690.	127.3	128.9	130.8	135.4	140.7	147.0	154.4	158.5	163.0	167.8
710.	131.1	132.6	134.5	138.9	143.9	149.8	156.7	160.4	164.5	168.8
730.	134.9	136.4	138.2	142.4	147.2	152.8	159.1	162.6	166.3	170.3
750.	138.7	140.1	141.9	145.9	150.5	155.8	161.8	165.0	168.5	172.1
770.	142.5	143.9	145.6	149.5	153.9	158.9	164.5	167.6	170.8	174.2

Table 7. (Continued)

	P, 10^{-2} psi									
T, ^{o}R	14.0	15.0	16.0	17.0	18.0	19.0	20.0	25.0	30.0	35.0
330.										
350.	2243.3	2253.1	2262.9	2272.6	2282.4	2292.1	2301.8	2350.4	2398.8	2447.0
370.	1904.0	1912.9	1921.7	1930.6	1939.4	1948.2	1957.0	2000.7	2044.0	2087.1
390.	1633.7	1641.9	1650.1	1658.3	1666.5	1674.7	1682.8	1723.1	1762.9	1802.3
410.	1413.1	1421.0	1428.9	1436.7	1444.5	1452.2	1459.9	1498.0	1535.4	1572.1
430.	1229.3	1237.1	1244.8	1252.4	1260.0	1267.6	1275.1	1311.8	1347.6	1382.5
450.	1073.0	1080.8	1088.5	1096.2	1103.8	1111.3	1118.7	1155.1	1190.1	1223.9
470.	937.1	945.2	953.2	961.1	968.9	976.6	984.2	1020.9	1055.8	1089.1
490.	816.2	825.0	833.6	842.0	850.2	858.3	866.2	904.2	939.6	973.1
510.	704.0	714.4	724.3	733.9	743.3	752.3	760.9	801.1	837.8	871.9
530.	595.0	607.4	619.2	630.4	641.2	651.5	678.9	707.0	747.3	782.7
550.	484.4	501.9	517.5	531.8	545.0	557.4	569.1	620.2	663.3	701.6
570.	344.1	382.4	409.6	431.4	450.0	466.4	481.2	541.1	588.2	628.5
590.	213.9	249.0	288.4	323.1	351.6	375.2	395.3	468.4	520.7	563.6
610.	188.3	203.5	222.7	245.7	270.6	295.1	317.8	402.7	460.5	506.0
630.	179.5	189.4	200.9	214.3	229.7	246.8	264.9	347.4	408.2	455.7
650.	175.3	183.2	191.6	201.0	211.4	223.1	235.8	305.4	364.9	412.7
670.	173.4	180.0	187.1	194.5	202.4	211.1	220.5	276.0	330.9	377.2
690.	173.0	178.6	184.6	191.1	197.7	204.6	212.0	256.3	305.0	348.7
710.	173.4	178.3	183.6	189.2	195.2	201.1	207.3	243.5	285.6	326.1
730.	174.5	178.9	183.6	188.5	193.8	199.3	204.7	235.2	271.4	308.3
750.	175.9	180.0	184.2	188.7	193.4	198.3	203.5	229.9	261.1	294.3
770.	177.7	181.5	185.4	189.5	193.7	198.2	202.8	226.6	253.8	283.5

Table 7. (Continued)

T, °R	P, 10^{-2} psi .2	1.0	2.0	4.0	6.0	8.0	10.0	11.0	12.0	13.0
800.	148.1	149.4	151.1	154.8	159.0	163.7	168.9	171.7	174.6	177.7
850.	157.4	158.7	160.2	163.7	167.5	171.8	176.5	179.0	181.6	184.3
900.	166.6	167.8	169.3	172.6	176.2	180.1	184.4	186.6	189.0	191.4
950.	175.6	176.8	178.3	181.4	184.8	188.5	192.5	194.5	196.7	198.9
1000.	184.6	185.8	187.2	190.2	193.4	196.9	200.7	202.6	204.6	206.7
1050.	193.5	194.6	196.0	198.9	202.1	205.4	209.0	210.8	212.7	214.6
1100.	202.2	203.4	204.7	207.6	210.7	213.9	217.3	219.1	220.9	222.7
1150.	210.8	212.0	213.4	216.3	219.3	222.5	225.8	227.5	229.2	230.9
1200.	219.4	220.6	222.0	224.9	227.9	231.0	234.3	235.9	237.6	239.3
1250.	227.8	229.0	230.5	233.4	236.5	239.6	242.9	244.5	246.2	247.8
1300.	236.1	237.4	239.0	242.0	245.1	248.3	251.6	253.2	254.9	256.5
1350.	244.4	245.8	247.4	250.6	253.9	257.1	260.4	262.1	263.8	265.5
1400.	252.6	254.1	255.8	259.3	262.7	266.1	269.5	271.2	272.9	274.6
1450.	260.7	262.3	264.3	268.0	271.7	275.3	278.9	280.7	282.5	284.2
1500.	268.7	270.6	272.8	277.0	281.0	284.9	288.7	290.6	292.5	294.3
1550.	276.7	278.9	281.4	286.2	290.8	295.1	299.3	301.3	303.3	305.2
1600.	284.6	287.4	290.4	296.2	301.4	306.3	310.9	313.2	315.3	317.4

Table 7. (Continued)

T, °R	P, 10^{-2} psi 14.0	15.0	16.0	17.0	18.0	19.0	20.0	25.0	30.0	35.0
800.	180.9	184.3	187.8	191.4	195.2	199.1	203.1	224.1	246.8	272.0
850.	187.1	190.0	193.0	196.1	199.3	202.6	205.9	224.3	241.9	261.4
900.	193.9	196.5	199.1	201.9	204.7	207.5	210.5	226.2	241.8	257.4
950.	201.2	203.5	205.9	208.4	210.9	213.4	216.1	229.9	244.7	257.5
1000.	208.8	210.9	213.1	215.4	217.6	220.0	222.4	234.8	248.1	260.2
1050.	216.6	218.6	220.6	222.7	224.8	227.0	229.2	240.6	252.7	264.8
1100.	224.6	226.5	228.4	230.4	232.3	234.4	236.4	247.0	258.1	269.7
1150.	232.7	234.5	236.4	238.3	240.1	242.1	244.0	253.9	264.3	275.0
1200.	241.1	242.8	244.6	246.4	248.2	250.0	251.9	261.3	271.1	281.1
1250.	249.5	251.3	253.0	254.7	256.5	258.3	260.0	269.1	278.4	287.9
1300.	258.2	259.9	261.6	263.3	265.0	266.8	268.5	277.3	286.3	295.4
1350.	267.1	266.8	270.5	272.2	273.9	275.6	277.3	286.0	294.7	303.4
1400.	276.4	278.1	279.8	281.5	283.2	284.9	286.6	295.1	303.6	312.1
1450.	286.0	287.7	289.5	291.2	292.9	294.6	296.4	304.9	313.3	321.6
1500.	296.2	298.0	299.8	301.5	303.3	305.1	306.8	315.4	323.8	332.0
1550.	307.2	309.1	311.0	312.8	314.6	316.5	318.3	327.0	335.4	343.6
1600.	319.5	321.5	323.5	325.5	327.4	329.3	331.2	340.1	348.6	356.8

Table 8. The thermal conductivity of a mixture of 12% CO_2 and 88% N_2O. Units as for pure N_2O.

T, °R	P, 10^{-2} psi .2	1.0	2.0	4.0	6.0	8.0	10.0	11.0	12.0	13.0
330.	113.71	113.94	114.20	114.72	115.24	115.76	116.28	116.54	116.80	117.05
350.	5.72	105.40	105.67	106.21	106.75	107.29	107.82	108.09	108.35	108.61
370.	6.06	97.48	97.77	98.34	98.91	99.47	100.02	100.30	100.57	100.84
390.	6.41	90.03	90.34	90.95	91.55	92.15	92.74	93.03	93.32	93.61
410.	6.75	7.48	83.26	83.92	84.58	85.22	85.86	86.17	86.48	86.79
430.	7.10	7.79	76.40	77.15	77.88	78.59	79.28	79.63	79.96	80.30
450.	7.45	8.10	8.87	70.50	71.34	72.15	72.93	73.31	73.69	74.06
470.	7.80	8.42	9.12	63.82	64.83	65.79	66.70	67.14	67.57	67.99
490.	8.15	8.74	9.39	11.03	58.15	59.37	60.47	61.00	61.51	62.01
510.	8.51	9.07	9.67	11.12	50.71	52.40	53.90	54.59	55.25	55.88
530.	8.87	9.40	9.97	11.27	13.22	45.32	47.28	48.15	48.96	49.72
550.	9.23	9.74	10.27	11.45	13.06	15.92	25.59	42.55	43.42	44.28
570.	9.59	10.08	10.59	11.67	13.05	15.11	18.91	22.37	28.96	37.86
590.	9.96	10.43	10.91	11.92	13.12	14.75	17.22	18.99	21.29	24.41
610.	10.34	10.79	11.25	12.18	13.26	14.62	16.45	17.64	19.06	20.73
630.	10.72	11.16	11.59	12.47	13.45	14.62	16.08	16.97	17.98	19.13
650.	11.11	11.53	11.95	12.78	13.68	14.71	15.94	16.65	17.43	18.29
670.	11.51	11.92	12.32	13.10	13.94	14.87	15.94	16.53	17.17	17.86
690.	11.91	12.31	12.69	13.45	14.23	15.09	16.04	16.55	17.10	17.68
710.	12.32	12.71	13.08	13.80	14.55	15.34	16.21	16.67	17.15	17.66
730.	12.74	13.12	13.48	14.18	14.88	15.63	16.43	16.86	17.30	17.75
750.	13.17	13.53	13.89	14.56	15.24	15.95	16.70	17.09	17.50	17.92
770.	13.60	13.96	14.31	14.96	15.61	16.29	17.00	17.37	17.75	18.14

Table 8. (Continued)

T, ^{o}R	P, 10^{-2} psi 14.0	15.0	16.0	17.0	18.0	19.0	20.0	25.0	30.0	35.0
330.										
350.	108.88	109.14	109.40	109.66	109.92	110.18	110.44	111.72	112.99	114.25
370.	101.12	101.39	101.66	101.93	102.20	102.46	102.73	104.05	105.35	106.62
390.	93.89	94.18	94.46	94.74	95.02	95.30	95.58	96.95	98.29	99.60
410.	87.09	87.40	87.70	88.00	88.29	88.59	88.88	90.32	91.72	93.08
430.	80.63	80.96	81.28	81.61	81.92	82.24	82.55	84.08	85.56	86.98
450.	74.43	74.79	75.14	75.50	75.84	76.19	76.53	78.17	79.74	81.24
470.	68.41	68.81	69.21	69.60	69.99	70.37	70.75	72.54	74.23	75.83
490.	62.49	62.96	63.42	63.87	64.31	64.73	65.16	67.15	68.98	70.70
510.	56.49	57.08	57.64	58.19	58.72	59.23	59.71	61.95	63.97	65.83
530.	50.44	51.14	51.80	52.43	53.05	53.64	55.55	56.85	59.18	61.20
550.	45.08	45.84	46.56	47.25	47.90	48.54	49.16	51.98	54.47	56.73
570.	40.12	41.25	42.16	42.95	43.66	44.32	44.95	47.78	50.29	52.59
590.	28.38	32.43	35.50	37.58	39.05	40.16	41.06	44.27	46.75	49.00
610.	22.74	25.06	27.59	30.09	32.35	34.27	35.86	40.78	43.64	45.91
630.	20.42	21.87	23.46	25.17	26.95	28.72	30.41	36.72	40.43	43.03
650.	19.24	20.28	21.38	22.57	23.82	25.14	26.48	32.67	37.02	40.08
670.	18.61	19.41	20.27	21.16	22.09	23.06	24.08	29.36	33.81	37.17
690.	18.30	18.96	19.65	20.39	21.12	21.88	22.68	26.98	31.15	34.55
710.	18.20	18.76	19.35	19.96	20.60	21.23	21.87	25.41	29.11	32.40
730.	18.23	18.72	19.24	19.77	20.33	20.90	21.45	24.41	27.64	30.72
750.	18.35	18.80	19.26	19.74	20.23	20.74	21.26	23.82	26.63	29.45
770.	18.54	18.95	19.38	19.81	20.26	20.72	21.19	23.49	25.97	28.53

Table 8. (Continued)

	P, 10^{-2} psi									
T, ^oR	.2	1.0	2.0	4.0	6.0	8.0	10.0	11.0	12.0	13.0
800.	14.28	14.62	14.96	15.58	16.20	16.84	17.50	17.85	18.19	18.55
850.	15.44	15.77	16.09	16.68	17.26	17.84	18.45	18.76	19.07	19.39
900.	16.67	16.99	17.29	17.85	18.39	18.94	19.50	19.79	20.07	20.36
950.	17.96	18.26	18.56	19.09	19.61	20.13	20.66	20.93	21.19	21.46
1000.	19.31	19.61	19.89	20.41	20.91	21.41	21.91	22.16	22.41	22.67
1050.	20.72	21.01	21.29	21.80	22.29	22.77	23.25	23.49	23.73	23.97
1100.	22.20	22.48	22.76	23.26	23.73	24.20	24.67	24.90	25.14	25.37
1150.	23.73	24.01	24.29	24.78	25.26	25.72	26.18	26.41	26.63	26.86
1200.	25.32	25.61	25.88	26.38	26.85	27.31	27.77	27.99	28.22	28.44
1250.	26.97	27.26	27.53	28.04	28.52	28.98	29.44	29.66	29.89	30.11
1300.	28.67	28.96	29.25	29.76	30.25	30.73	31.19	31.42	31.64	31.87
1350.	30.42	30.72	31.02	31.56	32.07	32.56	33.03	33.26	33.49	33.72
1400.	32.22	32.54	32.85	33.42	33.96	34.47	34.96	35.20	35.44	35.68
1450.	34.06	34.40	34.74	35.36	35.93	36.48	37.00	37.25	37.50	37.75
1500.	35.95	36.32	36.70	37.38	38.01	38.60	39.16	39.43	39.70	39.96
1550.	37.89	38.30	38.73	39.50	40.21	40.86	41.48	41.78	42.06	42.34
1600.	39.86	40.35	40.86	41.77	42.59	43.33	44.03	44.35	44.67	44.98

Table 8. (Continued)

	P, 10^{-2} psi									
T, ^{o}R	14.0	15.0	16.0	17.0	18.0	19.0	20.0	25.0	30.0	35.0
800.	18.92	19.29	19.67	20.06	20.46	20.86	21.28	23.33	25.42	27.62
850.	19.71	20.04	20.37	20.71	21.05	21.40	21.75	23.58	25.24	26.98
900.	20.66	20.95	21.25	21.56	21.86	22.17	22.49	24.09	25.60	27.03
950.	21.73	22.01	22.28	22.56	22.84	23.12	23.41	24.85	26.32	27.51
1000.	22.92	23.18	23.44	23.70	23.96	24.22	24.48	25.81	27.16	28.31
1050.	24.22	24.46	24.70	24.95	25.19	25.44	25.69	26.93	28.17	29.37
1100.	25.61	25.84	26.07	26.31	26.54	26.78	27.01	28.19	29.36	30.52
1150.	27.09	27.32	27.54	27.77	28.00	28.22	28.45	29.57	30.69	31.79
1200.	28.67	28.89	29.11	29.33	29.55	29.77	29.99	31.08	32.15	33.20
1250.	30.33	30.55	30.77	30.99	31.21	31.43	31.64	32.71	33.75	34.76
1300.	32.09	32.31	32.53	32.75	32.97	33.18	33.40	34.45	35.47	36.46
1350.	33.95	34.17	34.40	34.62	34.83	35.05	35.27	36.32	37.33	38.30
1400.	35.91	36.14	36.37	36.59	36.82	37.04	37.25	38.31	39.32	40.29
1450.	37.99	38.23	38.47	38.70	38.93	39.15	39.38	40.45	41.47	42.43
1500.	40.21	40.47	40.71	40.96	41.19	41.43	41.66	42.77	43.80	44.77
1550.	42.62	42.89	43.15	43.41	43.66	43.90	44.14	45.29	46.35	47.33
1600.	45.28	45.57	45.85	46.12	46.39	46.65	46.91	48.11	49.19	50.19

Table 9. The viscosity of a mixture of 6% CO_2 and 94% N_2O.

T, ^oR	P, 10^{-2} psi .2	1.0	2.0	4.0	6.0	8.0	10.0	11.0	12.0	13.0
330.	2551.0	2560.4	2571.4	2593.6	2615.7	2637.8	2660.0	2671.0	2682.1	0.0
350.	62.0	2136.6	2146.5	2166.2	2185.9	2205.5	2225.2	2235.0	2244.8	2254.6
370.	65.7	1806.0	1815.1	1833.2	1851.2	1869.2	1887.1	1896.0	1904.9	1913.8
390.	69.5	1540.8	1549.4	1566.6	1583.6	1600.5	1617.3	1625.6	1633.9	1642.2
410.	73.2	76.7	1330.8	1347.6	1364.2	1380.5	1396.7	1404.7	1412.7	1420.7
430.	77.0	80.3	1146.3	1163.3	1179.9	1196.3	1212.3	1220.3	1228.1	1236.0
450.	80.8	83.9	88.2	1003.9	1021.3	1038.2	1054.7	1062.8	1070.8	1078.7
470.	84.7	87.5	91.5	861.9	880.9	899.2	916.8	925.3	933.7	942.0
490.	88.5	91.2	94.8	104.8	751.9	772.9	792.6	802.0	811.3	820.2
510.	92.3	94.8	98.2	107.0	619.7	648.2	673.4	685.1	696.3	707.1
530.	96.2	98.5	101.6	109.5	121.4	514.1	552.3	568.3	582.6	596.3
550.	100.0	102.2	105.1	112.3	122.3	138.0	184.0	432.8	460.3	482.0
570.	103.9	105.9	108.6	115.2	124.0	136.4	156.3	173.6	212.5	315.1
590.	107.7	109.7	112.2	118.3	126.1	136.6	151.2	161.2	174.3	192.6
610.	111.6	113.4	115.8	121.5	128.6	137.7	149.6	157.1	166.0	176.7
630.	115.4	117.2	119.4	124.7	131.3	139.4	149.6	155.7	162.7	170.7
650.	119.3	120.9	123.1	128.1	134.2	141.6	150.5	155.8	161.6	168.1
670.	123.1	124.7	126.8	131.5	137.2	144.0	152.1	156.7	161.7	167.2
690.	126.9	128.4	130.4	134.9	140.3	146.6	154.0	158.1	162.6	167.4
710.	130.7	132.2	134.1	138.4	143.5	149.4	156.2	160.0	164.0	168.4
730.	134.5	135.9	137.6	141.9	146.7	152.3	158.6	162.1	165.6	169.8
750.	138.2	139.6	141.4	145.4	150.0	155.3	161.2	164.5	167.9	171.6
770.	142.0	143.4	145.1	148.9	153.3	158.4	164.0	167.0	170.3	173.6

Table 9. (Continued)

T, °R	P, 10^{-2} psi 14.0	15.0	16.0	17.0	18.0	19.0	20.0	25.0	30.0	35.0
330.										
350.	2264.3	2274.1	2283.9	2293.6	2303.4	2313.2	2322.9	2371.5	2420.0	2468.4
370.	1922.7	1931.5	1940.4	1949.2	1958.0	1966.8	1975.6	2019.3	2062.8	2105.9
390.	1650.5	1658.7	1666.9	1675.1	1683.3	1691.4	1699.6	1739.9	1779.6	1819.0
410.	1428.6	1436.4	1444.3	1452.0	1459.8	1467.5	1475.2	1513.2	1550.5	1587.1
430.	1243.7	1251.4	1259.1	1266.7	1274.2	1281.7	1289.2	1325.8	1361.5	1396.3
450.	1086.5	1094.3	1102.0	1109.6	1117.1	1124.6	1132.0	1168.1	1202.9	1236.6
470.	950.1	958.2	966.1	973.9	981.6	989.2	996.7	1033.1	1067.7	1100.9
490.	829.0	837.6	846.1	854.3	862.4	870.4	878.3	915.8	950.9	984.1
510.	717.4	727.5	737.2	746.6	755.5	764.1	772.6	812.2	848.5	882.3
530.	609.0	621.0	632.4	643.3	653.7	663.8	673.5	718.2	757.6	792.6
550.	500.5	516.6	531.6	545.2	557.9	569.8	581.1	631.0	673.5	711.3
570.	369.4	401.9	426.3	446.3	463.8	479.3	493.5	551.6	597.8	637.7
590.	221.2	262.5	304.4	338.7	366.0	388.4	407.6	473.4	529.8	572.1
610.	189.7	206.3	227.5	252.8	279.5	304.8	327.8	411.8	468.8	513.8
630.	179.9	190.2	202.4	216.6	233.1	251.4	270.5	354.6	415.4	462.6
650.	175.3	183.4	192.1	201.8	212.8	225.0	238.4	310.5	370.7	418.6
670.	173.3	179.9	187.2	194.7	202.9	211.9	221.7	279.3	335.2	381.9
690.	172.7	178.4	184.5	191.1	197.7	204.8	212.5	258.3	308.1	352.3
710.	173.0	178.0	183.3	189.0	195.1	201.0	207.3	244.6	287.7	328.8
730.	174.0	178.5	183.2	188.2	193.5	199.1	204.5	235.7	272.8	310.3
750.	175.4	179.5	183.8	188.3	193.0	198.0	203.2	230.1	261.9	295.8
770.	177.2	180.9	184.9	189.0	193.3	197.7	202.4	226.5	254.3	284.5

Table 9. (Continued)

T, °R	P, 10^{-2} psi .2	1.0	2.0	4.0	6.0	8.0	10.0	11.0	12.0	13.0
800.	147.6	148.9	150.6	154.2	158.4	163.1	168.3	171.1	174.0	177.1
850.	156.8	158.1	159.6	163.1	166.9	171.1	175.8	178.3	180.9	183.6
900.	165.9	167.2	168.6	171.9	175.5	179.4	183.6	185.9	188.2	190.6
950.	174.9	176.1	177.6	180.6	184.0	187.7	191.6	193.7	195.9	198.1
1000.	183.8	185.0	186.4	189.4	192.6	196.1	199.3	201.7	203.7	205.7
1050.	192.6	193.8	195.1	198.0	201.2	204.5	208.0	209.8	211.7	213.6
1100.	201.3	202.5	203.8	206.7	209.7	212.9	216.3	218.0	219.8	221.6
1150.	209.9	211.0	212.4	215.2	218.2	221.3	224.6	226.3	228.0	229.7
1200.	218.4	219.5	220.9	223.8	226.7	229.8	233.0	234.7	236.3	238.0
1250.	226.7	227.9	229.4	232.2	235.2	238.3	241.5	243.1	244.8	246.4
1300.	235.0	236.3	237.7	240.7	243.8	246.9	250.1	251.7	253.3	255.0
1350.	243.2	244.5	246.1	249.2	252.4	255.6	258.8	260.4	262.1	263.7
1400.	251.3	252.8	254.4	257.7	261.1	264.4	267.7	269.4	271.0	272.7
1450.	259.3	260.9	262.8	266.4	269.9	273.4	276.9	278.6	280.3	282.0
1500.	267.3	269.1	271.1	275.1	279.0	282.7	286.4	288.2	290.0	291.8
1550.	275.2	277.3	279.6	284.2	288.5	292.6	296.6	298.5	300.4	302.3
1600.	283.1	285.6	288.4	293.7	298.6	303.3	307.7	309.8	311.8	313.9

Table 9. (Continued)

T, °R	P, 10^{-2} psi 14.0	15.0	16.0	17.0	18.0	19.0	20.0	25.0	30.0	35.0
800.	180.3	183.7	187.2	190.8	194.6	198.5	202.6	223.8	246.9	272.5
850.	186.4	189.3	192.3	195.4	198.6	201.9	205.3	223.7	241.5	261.3
900.	193.1	195.7	198.4	201.1	203.9	206.7	209.7	225.4	241.1	257.0
950.	200.3	202.7	205.0	207.5	210.0	212.6	215.2	229.0	243.8	256.3
1000.	207.8	210.0	212.2	214.4	216.7	219.0	221.4	233.8	247.2	259.3
1050.	215.6	217.5	219.6	221.7	223.8	225.9	228.1	239.5	251.6	263.7
1100.	223.5	225.3	227.3	229.2	231.2	233.2	235.2	245.8	256.9	268.4
1150.	231.5	233.3	235.1	237.0	238.9	240.8	242.7	252.6	262.9	273.6
1200.	239.7	241.5	243.2	245.0	246.8	248.6	250.4	259.8	269.6	279.5
1250.	248.1	249.8	251.5	253.2	254.9	256.7	258.5	267.5	276.7	286.2
1300.	256.6	258.3	260.0	261.7	263.3	265.1	266.8	275.5	284.4	293.4
1350.	265.4	267.0	268.7	270.4	272.0	273.7	275.4	283.9	292.5	301.2
1400.	274.4	276.0	277.7	279.4	281.1	282.7	284.4	292.8	301.2	309.6
1450.	283.7	285.4	287.1	288.8	290.5	292.2	293.9	302.3	310.5	318.8
1500.	293.6	295.3	297.1	298.8	300.6	302.3	304.0	312.4	320.6	328.7
1550.	304.2	306.0	307.8	309.6	311.4	313.2	314.9	323.4	331.7	339.7
1600.	315.8	317.8	319.7	321.6	323.4	325.3	327.1	335.8	344.1	352.1

Table 10. The thermal conductivity of a mixture of 6% CO_2 and 94% N_2O.

T, °R	P, 10^{-2} psi: .2	1.0	2.0	4.0	6.0	8.0	10.0	11.0	12.0	13.0
330.	113.92	114.14	114.40	114.91	115.43	115.94	116.46	116.71	116.97	0.00
350.	5.71	105.67	105.94	106.48	107.01	107.54	108.07	108.33	108.59	108.85
370.	6.05	97.82	98.11	98.67	99.23	99.78	100.33	100.60	100.87	101.14
390.	6.39	90.44	90.74	91.34	91.94	92.53	93.11	93.39	93.68	93.96
410.	6.74	7.47	83.72	84.38	85.02	85.66	86.28	86.59	86.90	87.20
430.	7.08	7.78	76.93	77.67	78.38	79.08	79.77	80.10	80.43	80.76
450.	7.43	8.09	8.85	71.10	71.91	72.70	73.47	73.84	74.21	74.58
470.	7.78	8.40	9.10	64.51	65.49	66.42	67.30	67.73	68.15	68.57
490.	8.13	8.72	9.37	11.02	58.94	60.09	61.16	61.67	62.16	62.64
510.	8.48	9.04	9.65	11.10	51.67	53.27	54.71	55.37	56.01	56.62
530.	8.84	9.37	9.94	11.25	13.23	46.25	48.13	48.96	49.75	50.49
550.	9.20	9.71	10.25	11.43	13.06	16.04	30.68	43.21	44.11	44.95
570.	9.56	10.05	10.56	11.65	13.03	15.15	19.22	23.24	32.26	39.86
590.	9.93	10.40	10.88	11.89	13.10	14.77	17.34	19.23	21.76	25.29
610.	10.31	10.76	11.21	12.15	13.24	14.61	16.51	17.74	19.24	21.04
630.	10.58	11.12	11.56	12.44	13.42	14.60	16.10	17.02	18.07	19.27
650.	11.07	11.49	11.91	12.74	13.64	14.68	15.93	16.66	17.46	18.36
670.	11.46	11.67	12.27	13.06	13.90	14.84	15.91	16.52	17.17	17.89
690.	11.86	12.26	12.64	13.40	14.18	15.04	16.00	16.52	17.08	17.68
710.	12.27	12.65	13.03	13.75	14.49	15.29	16.16	16.63	17.12	17.63
730.	12.66	13.06	13.42	14.12	14.82	15.57	16.38	16.80	17.25	17.71
750.	13.10	13.47	13.82	14.50	15.17	15.88	16.64	17.03	17.44	17.86
770.	13.54	13.69	14.24	14.39	15.54	16.22	16.93	17.30	17.66	18.07

Table 10. (Continued)

T, ^{o}R	P, 10^{-2} psi 14.0	15.0	16.0	17.0	18.0	19.0	20.0	25.0	30.0	35.0
330.										
350.	109.11	109.37	109.63	109.89	110.14	110.40	110.66	111.93	113.19	114.43
370.	101.41	101.68	101.95	102.22	102.48	102.75	103.01	104.32	105.60	106.86
390.	94.25	94.53	94.81	95.09	95.36	95.64	95.91	97.27	98.59	99.89
410.	87.50	87.80	88.10	88.39	88.69	88.98	89.27	90.69	92.07	93.41
430.	81.09	81.41	81.73	82.05	82.36	82.68	82.98	84.49	85.95	87.35
450.	74.94	75.29	75.64	75.99	76.33	76.67	77.00	78.62	80.17	81.65
470.	68.97	69.37	69.76	70.14	70.52	70.90	71.26	73.03	74.69	76.27
490.	63.11	63.57	64.02	64.46	64.89	65.30	65.72	67.07	69.48	71.17
510.	57.21	57.78	58.33	58.87	59.36	59.84	60.31	62.50	64.49	66.32
530.	51.19	51.66	52.51	53.13	53.73	54.31	54.87	57.45	59.72	61.71
550.	45.74	46.49	47.20	47.88	48.53	49.16	49.77	52.56	55.03	57.25
570.	41.00	41.95	42.76	43.52	44.21	44.85	45.47	48.29	50.80	53.09
590.	29.83	34.02	36.82	38.61	39.88	40.86	41.67	44.73	47.20	49.44
610.	23.22	25.75	28.48	31.09	33.35	35.21	36.72	41.33	44.08	46.32
630.	20.64	22.17	23.87	25.70	27.58	29.42	31.15	37.36	40.93	43.45
650.	19.35	20.43	21.59	22.84	24.16	25.55	26.95	33.25	37.54	40.54
670.	18.66	19.49	20.38	21.29	22.27	23.29	24.35	29.30	34.27	37.61
690.	18.31	18.98	19.70	20.45	21.20	21.99	22.82	27.27	31.51	34.92
710.	18.18	18.75	19.35	19.98	20.63	21.27	21.94	25.58	29.36	32.69
730.	18.19	18.69	19.21	19.75	20.32	20.90	21.46	24.50	27.80	30.92
750.	18.30	18.75	19.22	19.70	20.20	20.71	21.24	23.85	26.72	29.59
770.	18.48	18.89	19.32	19.76	20.21	20.67	21.14	23.48	26.00	28.60

Table 10. (Continued)

T, ^{o}R	P, 10^{-2} psi .2	1.0	2.0	4.0	6.0	8.0	10.0	11.0	12.0	13.0
800.	14.20	14.55	14.88	15.50	16.12	16.76	17.42	17.76	18.11	18.47
850.	15.35	15.68	16.00	16.58	17.16	17.75	18.35	18.66	18.97	19.29
900.	16.56	16.88	17.18	17.74	18.28	18.83	19.39	19.67	19.96	20.24
950.	17.83	18.14	18.43	18.96	19.48	20.00	20.52	20.79	21.05	21.32
1000.	19.16	19.46	19.74	20.26	20.76	21.25	21.75	22.00	22.25	22.51
1050.	20.56	20.85	21.12	21.63	22.11	22.59	23.07	23.31	23.55	23.79
1100.	22.01	22.30	22.57	23.06	23.54	24.00	24.47	24.70	24.93	25.16
1150.	23.52	23.81	24.08	24.57	25.03	25.49	25.95	26.17	26.40	26.62
1200.	25.09	25.37	25.64	26.13	26.60	27.05	27.51	27.73	27.95	28.17
1250.	26.71	27.00	27.27	27.77	28.24	28.70	29.14	29.37	29.59	29.81
1300.	28.39	28.68	28.96	29.47	29.94	30.41	30.86	31.09	31.31	31.53
1350.	30.11	30.41	30.70	31.23	31.72	32.20	32.67	32.89	33.12	33.34
1400.	31.89	32.20	32.50	33.06	33.58	34.07	34.55	34.79	35.02	35.25
1450.	33.70	34.03	34.36	34.95	35.51	36.04	36.54	36.79	37.03	37.27
1500.	35.56	35.92	36.28	36.93	37.53	38.10	38.64	38.90	39.16	39.41
1550.	37.47	37.87	38.27	39.00	39.67	40.30	40.88	41.17	41.44	41.71
1600.	39.41	39.87	40.35	41.20	41.96	42.67	43.32	43.63	43.94	44.23

Table 10. (Continued)

T, °R	P, 10^{-2} psi									
	14.0	15.0	16.0	17.0	18.0	19.0	20.0	25.0	30.0	35.0
800.	18.84	19.21	19.59	19.98	20.38	20.79	21.21	23.28	25.40	27.63
850.	19.61	19.94	20.27	20.61	20.95	21.30	21.65	23.49	25.16	26.93
900.	20.54	20.83	21.13	21.44	21.74	22.05	22.37	23.97	25.48	26.93
950.	21.59	21.87	22.14	22.42	22.70	22.98	23.26	24.71	26.17	27.38
1000.	22.76	23.02	23.27	23.53	23.79	24.05	24.31	25.64	26.98	28.14
1050.	24.03	24.27	24.51	24.76	25.00	25.25	25.49	26.73	27.97	29.16
1100.	25.39	25.62	25.86	26.09	26.32	26.56	26.79	27.96	29.12	30.28
1150.	26.85	27.07	27.30	27.52	27.75	27.97	28.20	29.31	30.42	31.51
1200.	28.39	28.61	28.83	29.05	29.27	29.49	29.71	30.79	31.85	32.89
1250.	30.03	30.24	30.46	30.68	30.89	31.11	31.32	32.37	33.40	34.41
1300.	31.75	31.97	32.18	32.40	32.61	32.82	33.04	34.07	35.08	36.06
1350.	33.57	33.78	34.00	34.22	34.43	34.65	34.86	35.89	36.89	37.85
1400.	35.48	35.70	35.93	36.15	36.36	36.58	36.79	37.83	38.82	39.77
1450.	37.51	37.74	37.97	38.19	38.42	38.64	38.85	39.91	40.90	41.85
1500.	39.66	39.90	40.14	40.38	40.61	40.84	41.06	42.14	43.15	44.10
1550.	41.98	42.23	42.49	42.74	42.98	43.22	43.45	44.56	45.59	46.56
1600.	44.51	44.79	45.06	45.33	45.58	45.84	46.08	47.24	48.30	49.27

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The dilute gas coefficients, η^o and λ^o, have been correlated by the empirical equation (31). An alternative, however, is to consider the kinetic theory, statistical mechanical, expressions such as

$$\eta^o = \frac{5}{16} \frac{(\pi \underline{m}\, kT)^{1/2}}{\pi\sigma^2\, \Omega^{(2,2)*}} \tag{1A}$$

where $\underline{m}$ is the molecular mass, k is Boltzmann's constant and σ is a length parameter, characteristic of the intermolecular pair potential function, ϕ. The collision integral, $\Omega^{(2,2)*}$, is a function of ϕ and the temperature. Clearly one requires an expression for ϕ to use equation (1A) in practice.

The potential for a nonspherical molecule such as nitrous oxide can be written as the sum of a spherical contribution, ϕ_s (i.e., ϕ_s depends on the intermolecular separation between molecules but not on their relative orientations), and a nonspherical contribution, ϕ_{ns}, which incorporates the appropriate electrostatic moments and molecular polarizabilities. Hence

$$\phi = \phi_s + \phi_{ns} \tag{2A}$$

In previous work we have represented the spherical part by the m-6-8 potential function [32-34]:

$$\phi_s^* = \phi_s/\varepsilon = \frac{6+2\gamma}{m-6}\left(\frac{\sigma}{r}\right)^m d^m - \frac{m-\gamma(m-8)}{m-6}\left(\frac{\sigma}{r}\right)^6 d^6 - \gamma\left(\frac{\sigma}{r}\right)^3 d^8 \quad , \tag{3A}$$

where $d = r_{min}/\sigma$, with σ and r_{min} being defined by the conditions $\phi_s(\sigma) = 0$ and $\phi_s(r_m) = -\varepsilon$, respectively. The parameter m represents the 'hardness' of the repulsive term while γ represents the 'strength' of the inverse eighth attraction term.

It turns out that the viscosity coefficient is only weakly dependent on the nonspherical contribution so a fit of viscosity data with equation (1A) will determine the potential parameters of ϕ_s. Possible errors in making this simplication are discussed in reference [34].

Nitrous Oxide. Viscosity data, [6,7], of nitrous oxide was fitted to equation (1A) using the m-6-8 collision integrals from reference [36]. The parameters thus determined are

$$m = 11 \qquad \gamma = 3$$

$$\sigma = 3.65 \times 10^{-10}\ \mathrm{m} \qquad r_m = 4.068 \times 10^{-10}\mathrm{m} \tag{4A}$$

$$\varepsilon/k = 288.0\ \mathrm{K}$$

A deviation curve comparing calculated with experimental viscosity coefficients, as represented by the function (31), is shown as figure 3a. The deviation is systematic above 300 K, but well within the experimental uncertainty of the data.

The thermal conductivity coefficient was also determined from the corresponding kinetic theory expression. The result agreeded with experiment to within the estimated error of 6%. Details will not be given in this report.

The Second Virial Coefficient of Nitrous Oxide. It is often instructive to calculate the second virial coefficient, B, of a gas using the potential found suitable for the viscosity. The calculation is worthwhile in itself. Further, however, the second virial statistical mechanical expression and the second virial data are independent of the viscosity. The calculation is thus a valuable check on the potential, and on the viscosity measurements which led to the potential parameters.

For a polyatomic molecule, the nonspherical contribution to equation (1), ϕ_{ns}, has a significant effect on the second virial coefficient and cannot be neglected. In general one has

$$\phi_{ns} = \phi(\mathrm{permanent}) + \phi(\mathrm{induced}) \tag{5A}$$

where ϕ(permanent) represents interactions between the permanent moments —— e.g., dipole(μ)-dipole, quadrupole(Θ)-quadrupole, and dipole-quadrupole interactions —— while ϕ(induced) represents the contributions caused by the induction effects of the permanent moments.

Nitrous oxide is somewhat unusual in that it possesses a small dipole but a large quadrupole. In the brief discussion following, we will consider these moments but will exclude the effects of ϕ(induced). The potential for nitrous oxide is thus

$$\phi = \phi_s + \phi(\mu\mu) + \phi(\Theta\Theta) + \phi(\mu\Theta) \tag{6A}$$

where ϕ_s is the potential (3A) with the parameters of equation (4A); $\phi(\mu\mu)$, $\phi(\Theta\Theta)$ and $\phi(\mu\Theta)$ are the dipole-dipole, quadrupole-quadrupole, and dipole-quadrupole terms, respectively.

Writing the equation of state as

$$\frac{P}{\rho NkT} = 1 + B\rho + \ldots \tag{7A}$$

where N is Avogadro's number, the second virial coefficient is given formally by

$$B = \frac{1}{2}\iint [\exp(-\beta\phi)-1]\, d\underset{\sim}{R}_1\, d\underset{\sim}{R}_2 \tag{8A}$$

where $\beta = 1/kT$ and $\underset{\sim}{R}_1$ and $\underset{\sim}{R}_2$ denote the position and angular configuration of molecule 1 and 2, respectively.

Several techniques have been proposed to integrate equation (8A) of which the most common is the expansion procedure of Pople [37]. One considers the molecules to have point moments and to interact according to the coordinate system shown in figure 4.

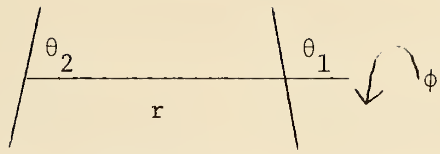


Figure 4.

Equation (2A) for ϕ is inserted into equation (8A) and the ϕ_{ns} term expanded in powers of β. The integrations over angles are then carried out to yield;

$$B^*(T^*) = B(kT/\varepsilon)/b_o = B^*_{m-6-8} + B_\mu + B_\Theta + B_{\mu\Theta} \tag{9A}$$

Here $b_o = 2\pi N\sigma^3/3$ and B^*_{m-6-8} is the conventional reduced second virial coefficient for the spherical potential, as tabulated in reference [36]. For the model shown in figure 4 one has for the dipole-dipole potential;

$$\phi_{\mu\mu} = -\frac{\mu^2}{r^3}\,[2\,\mathrm{Cos}\theta_1\,\mathrm{Cos}\theta_2 - \mathrm{Sin}\theta_1\,\mathrm{Sin}\theta_2\,\mathrm{Cos}\phi] \tag{10A}$$

For $\phi_{\Theta\Theta}$:

$$\begin{aligned}\phi_{\Theta\Theta} = \frac{3}{4}\,\frac{\Theta^2}{r^5}\,[1 &- 5\,\mathrm{Cos}^2\theta_1 - 5\,\mathrm{Cos}^2\theta_2 - 15\,\mathrm{Cos}^2\theta_1\,\mathrm{Cos}^2\theta_2 \\ &+ 2(\mathrm{Sin}\theta_1\,\mathrm{Sin}\theta_2\,\mathrm{Cos}\phi - 4\,\mathrm{Cos}\theta_1\,\mathrm{Cos}\theta_2)^2]\end{aligned} \tag{11A}$$

And for $\phi_{\mu\Theta}$:

$$\begin{aligned}\phi_{\mu\Theta} = \frac{3}{2r^4}\,\mu\Theta\,[(\mathrm{Cos}\theta_2 &- \mathrm{Cos}\theta_1)(3\,\mathrm{Cos}\theta_1\,\mathrm{Cos}\theta_2 - 2\,\mathrm{Sin}\theta_1\,\mathrm{Sin}\theta_2\,\mathrm{Cos}\phi) \\ &- \mathrm{Cos}\theta_1 + \mathrm{Cos}\theta_2]\end{aligned} \tag{12A}$$

Hence expressions for B_μ, B_Θ and $B_{\mu\Theta}$ are

$$B_\mu = -192 \sum_{j=1}^{\infty} \left[\frac{j!}{(2j+1)!}\right]^2 \mu^{*4j} K_j I_{6j} \frac{2^{2(j-3)}}{T^{*2j}} \tag{13A}$$

where $\mu^{*2} = \mu^2/\varepsilon\sigma^3$ and

$$K_j = \sum_{k=o}^{j} (2k)!/(k!)^2 \tag{14A}$$

$$B_\Theta = -\frac{21}{5} \frac{\Theta^4}{T^{*2}} I_{10} + \frac{216}{245} \frac{\Theta^{*6}}{T^{*3}} I_{15} + \ldots \tag{15A}$$

where $\Theta^{*2} = \Theta^2/\varepsilon\sigma^5$ and finally

$$B_{\mu\Theta} = -\frac{3\mu^{*2}\,\Theta^{*2}}{T^{*2}} \left[I_8 - \frac{4}{5} \frac{\mu^{*2}}{T^*} I_{11}\right] + \frac{72}{35} \frac{\mu^{*2}\,\Theta^4}{T^{*3}} I_{13} + \ldots \tag{16A}$$

Note that equations (13A), (15A) and (16A) are expansions for which only the first few terms are considered. The index, j, of equation (13A) is set equal to 4.

The above equations contain integrals I_x given by

$$I_x = \int_o^\infty \exp\left[-\beta\phi_s^* (r^*)\right] (r^*)^{-x+2}\, dr^* \tag{17A}$$

where $r^* = r/\sigma$.

The Pople expansion technique has the advantage that the integration over angles only has to be carried out once. Hence the calculation of the second virial using a particular spherical potential reduces to the straightforward integrations of equation (17A); the results of which can be tabulated for a given spherical potential.

Returning to nitrous oxide: values for the moments are [38]†

$$\Theta = 3.0 \times 10^{-26} \text{ e.s.u.}$$
$$\mu = 0.166 \times 10^{-18} \text{ e.s.u.} \tag{18A}$$

Insertion of these parameters into the expression for B^*, equation (9A), led to the graph shown as figure 3b. Also included in this figure are the data points of Hirth and Kobe [30].

It can be seen that our prediction of the second virial is not unsatisfactory but the predicted values are consistently somewhat higher. Possible reasons for the discrepancy are 1) neglect of the induction contribution to B^*, 2) lack of convergence of the expansions since the quadrupole moment of nitrous oxide is relatively large and 3) uncertainty in the m-6-8 parameters. Unfortunately, we cannot correct this last factor. We have shown that the m-6-8 parameters should be selected from viscosity data taken over a wide temperature range (see the discussion in reference [32]) but the data is limited for nitrous oxide. We did, however, investigate 2) as remarked in the next section.

Direct Calculation of the Second Virial Coefficient. There are some drawbacks in the expansion (9A). For example, all I integrals have to be redetermined if the spherical potential is modified and, of interest here, the arbitrary truncation of the expansions can introduce convergence problems. Several authors have investigated alternative methods to the expansion of the exponential term in equation (8A). The most direct is to carry the full integration numerically using, for example, the Monte-carlo approach. This and other integration schemes are discussed by Stroud [39].

Steele and Sweet [40] discuss a procedure in which the potential function, $\phi(r, \theta_1\ \theta_2\ \phi)$, and the radial distribution function, $g(r, \theta_1\ \theta_2\ \phi)$, are expanded in spherical harmonics and the integrations over angles performed numerically.

---

† 1 e.s.u. $\equiv 3.33564 \times 10^{-14}$ C m^2.

The virial coefficient follows from a straightforward integration over r — the intermolecular separation.

Our work with nitrous oxide here, and previously with carbon dioxide [34], suggested another integration technique which avoids the somewhat complex and time consuming calculations alluded to above, but which can eliminate the convergence problems of the expansion method. An outline of our procedure is as follows.

Consider the potential of equations (3A), (10A)-(12A) and the coordinate system of figure 4. The two molecules are set at fixed r apart at some initial relative angular orientation, e.g., $\theta_1 = \theta_2 = \phi = 0$. The angles are then varied incrementally (say in increments of $\pi/4$, $\pi/8$, etc.) over their range of integration ($\theta_1, \theta_2 \equiv \pi \quad \phi \equiv 2\pi$) and the numerical value of the angle dependent part of the potential recorded for each increment. Due, however, to the symmetry of the model, many of the values are identical so only the different, e, values and their weight, wt, (their fraction of the total) are recorded. The second virial coefficient for a given initial configuration follows after integrations over r according to the expression

$$B = 2\pi N \sum_{i=1}^{e} \left\{ \frac{(sswt)_i \int_o^\infty \left(1 - e^{\frac{-\phi_i(r,\ \theta_1,\ \theta_2,\ \phi)}{kT}}\right)}{\sum_{i=1}^{e} (sswt)_i} r^2\, dr \right\} \tag{19A}$$

where

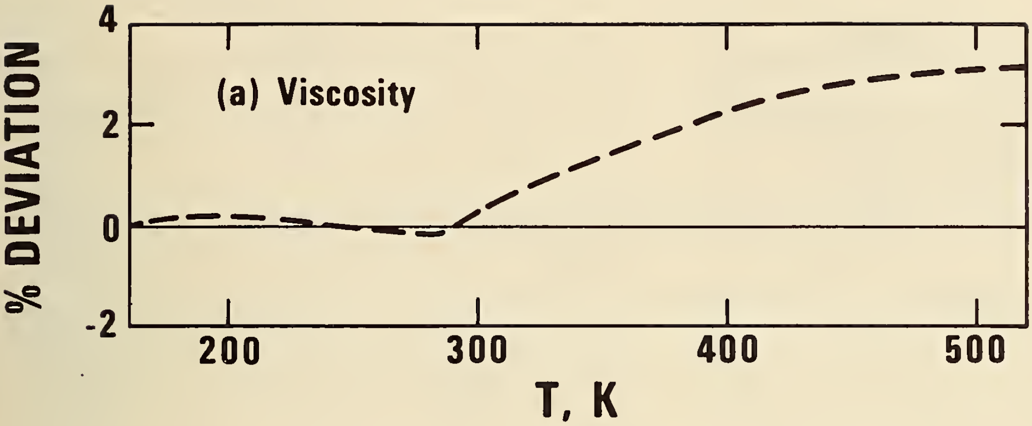
$$(sswt)_i = (\mathrm{Sin}\theta_1\ \mathrm{Sin}\theta_2\ wt)_i \qquad i = 1,\ e \tag{20A}$$

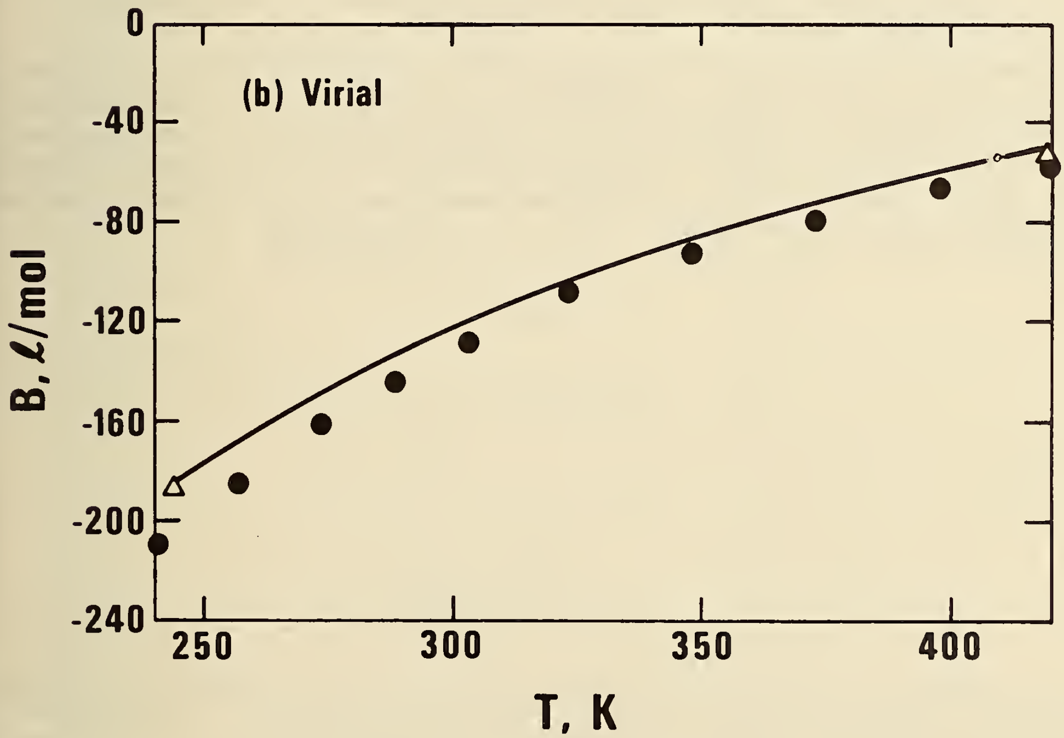
Details of the calculation will be published elsewhere. Values of B for two initial configurations at two temperatures were determined and are shown as triangles in figure 3b. One can conclude that the expansion procedure, shown by the curve, did indeed underestimate slightly the virial.

It should be stressed that the calculations of the second virial coefficient are predictions: one could get better agreement with experiment, without affecting significantly the viscosity fit, by adjusting the potential parameters.

Finally, we conclude from the calculation of the second virial that our assessment of about $\pm$ 3% accuracy in the viscosity data is reasonable.

Figure 3(a). Viscosity coefficient of dilute N_2O: comparison between kinetic theory values and equation (31). 3(b). Plot of the second virial, B, versus temperature. Data, filled circles, from reference [30]. The curve is from equation (9A), while the triangles are results discussed in the text.


(a) Viscosity
% DEVIATION
4
2
0
-2
200
300
400
500
T, K


(b) Virial
B, ℓ/mol
0
-40
-80
-120
-160
-200
-240
250
300
350
400
T, K

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The viscosity and thermal conductivity coefficients of nitrous oxide are calculated for temperatures between 180 and 900 K (330 to 1600°R) for pressures to 23 MPa (∿ 3500 psi). Tables of values are presented. Two mixtures with carbon dioxide are also discussed. These transport coefficients (for the pure fluid and for the mixtures) were predicted from thermodynamic data. Details of the prediction procedure are presented. Estimates of the accuracy of the tabular values are ± 6% for the viscosity and ± 8% for the thermal conductivity.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* Carbon dioxide; corresponding states; mixtures; nitrous oxide; prediction; thermal conductivity; transport property; viscosity.

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